

LITERATURE REVIEW OF

**SCIENTIFIC STUDIES SUPPORTING
THE EFFICACY OF SURFACE
ELECTROMYOGRAPHY, LOW FREQUENCY
TENS AND MANDIBULAR TRACKING FOR
OCCLUSION EVALUATION AND AIDS IN THE
DIAGNOSIS & TREATMENT OF TMD.**

PREPARED BY

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FORWARD

ICCMO is the unquestioned international scientific authority for neuromuscular dentistry.

There is a huge body of science forming the foundation for the use of advanced technologies to aid in the diagnosis and treatment of occlusion and TMD. The clinical protocols for neuromuscular diagnosis and treatment are based upon the most extensive body of scientific literature in the field of occlusion and temporomandibular disorders. This body of literature has sustained the validity of the science supporting neuromuscular dental principles after the most intense scrutiny by both the American Dental Association (ADA) and the United States Food & Drug Administration (FDA). It is no coincidence that Neuromuscular Dentistry has a 45 year history of clinical success. Neuromuscular clinical techniques are founded on the most compelling foundation of scientific research and facts. This literature review supports the efficacy of Low frequency TENS, surface electromyography and mandibular tracking for occlusion evaluation and as aids in the diagnosis and treatment of TMD. It is designed for ICCMO members to easily access, reference and reproduce this body of scientific support for Neuromuscular Dentistry.

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LITERATURE REVIEW OF SCIENTIFIC STUDIES SUPPORTING
THE EFFICACY OF SURFACE ELECTROMYOGRAPHY
IN THE DIAGNOSIS AND TREATMENT OF TMD
(SURFACE ELECTROMYOGRAPHY)

INTRODUCTION

There are numerous studies that support the physiological basis for using quantitative electromyography in the diagnosis of temporomandibular disorders (Moyers, 1949; Perry, 1954; Jarabak, 1956; Perry, 1957; Porritt, 1960; Grossman, 1961; Moller, 1966; Yemm, 1976; Bakke et al., 1980; Riise et al., 1982; Sheikholeslam et al., 1983; Riise et al., 1984; Kydd et al. 1986).

There is evidence, based on controlled studies that used extensive statistical tests, that surface electromyography is reliable and reproducible (Goldensohn, 1966; Lloyd, 1971; Mitani and Yamashita, 1978; Riise, 1983; Hermens et al., 1986; Burdette and Gale, 1987).

Controlled studies that used extensive statistical tests show that there is a strong relationship between EMG and muscular force (Lippold, 1952; Bigland et al., 1954; Molin, 1972; Milner-Brown, 1975; Pruijm, 1978).

Several studies have quantitatively investigated the EMG during postural activity of the mandible and during maximal bite in the intercuspal position. The EMG values for the temporal and masseteric muscles have been quantitatively investigated in these studies for control subjects without functional disorders and for patients with functional disorders. (Lous et al., 1970; Moller et al., 1971; Sheikholeslam et al., 1980; Sheikholeslam et al., 1982; Moller et al., 1982; Cram and Engstrom, 1986). These studies replicated the results that quantified statistically significant differences between the normal population and the patient population. The slight variability among these studies was due to the type of EMG instrumentation used in each study (i.e. range of filter frequency).

There is evidence based on controlled studies that used extensive statistical tests that maximal bite force and the electrical muscle activity during maximal bite in the intercuspal position are significantly weaker in patients with functional disorders of the masticatory system than controls without such disorders (Molin, 1972; Helkimo et al., 1975; Randow et al., 1976; Sheikholeslam et al., 1980; Moller et al., 1982; Sheikholeslam et al., 1982; Kydd et al., 1986).

Controlled studies that used extensive statistical tests conclude that postural activity of temporalis and masseter muscles are significantly higher in patients with functional disorders of the masticatory system than controls without such disorders (Moller, 1966; Lous et al., 1970; Moller et al., 1971; Sheikholeslam et al., 1982; Pantaleo et al., 1983; Geraris et al., 1989).

Clinical studies investigating Electromyography of temporal and masseteric muscles concluded that EMG was effective in the diagnosis of Myofascial Pain Disorders (Sheikholeslam et al., 1986; Pantaleo et al., 1983; Cooper et al, 1986; Moller, 1969; Helkimo et al., 1975; Mylinski et al., 1985; Riise et al., 1982; Sheikholeslam et al, 1983; Riise et al., 1984.) These studies further validate the basis for the use of EMG in clinical dentistry. The patients examined in the above studies exhibited high levels of EMG postural activity and weak EMG activity during maximal bite in the intercuspal position. Occlusal therapy resulted in significant improvement in symptoms and pain, and the successfully treated patients had significantly lower postural activity and significantly improved and symmetrical maximal bite activity. The rationale for utilizing EMG to monitor response to occlusal therapy was further substantiated when occlusal splints were removed causing onset of pain and elevated postural activity.

In summary, based on well controlled empirical and clinical studies that have been conducted in several universities over the past three decades throughout the world, there is unequivocal evidence to strongly support the use of EMG for the evaluation and diagnosis of temporomandibular disorders.

ARTICLES REVIEWED IN THIS PUBLICATION**SECTION 1: STUDIES THAT DOCUMENT THE PHYSIOLOGICAL BASIS FOR THE EFFICACY OF ELECTROMYOGRAPHY IN DENTISTRY**

1. Vig, P. Electromyography in dental science: A review. Australian Dental Journal, pp. 315-322, August, 1963. See Abstract on page 7.
2. Jarabak, J.R. An electromyographic analysis of muscular and temporomandibular joint disturbances due to imbalances in occlusion. Angle Orthodont., (26)3: 170-190, 1956. See Abstract on page 9.
3. Perry, H.T. and S.C. Harris. Role of the neuromuscular system in functional activity of the mandible. Journal of Am. Dent. Assoc., 48: 665-673, 1954. See Abstract on page 12.
4. Perry, H. T. Muscular changes associated with temporomandibular joint dysfunction. Journal of Am. Dent. Res., 54: 644-653, 1957. See Abstract on page 14.
5. Yemm, R. Neurophysiologic studies of temporomandibular joint dysfunction. Oral Sci. Rev., 7: 31-53, 1976. See Abstract on page 17.
6. Bakke, M. & Moller, E. Distortion of maximal elevator activity by unilateral premature tooth contact. Scand. J. Dent. Res., 80: 67-75, 1980. See Abstract on page 20.
7. Riise, C. and Sheikholeslam, A. The influence of experimental interfering occlusal contacts on the postural activity of the anterior temporal and masseter muscles in young adults. J. Oral Rehabilitation, 9: 419-425, 1982. See Abstract on page 21.
8. Sheikholeslam, A., and Riise, C. Influence of experimental interfering occlusal contacts on the activity of the anterior temporal and masseter muscles during submaximal and maximal bite in the intercuspal position. J. Oral Rehabilitation, 10: 207-214, 1983. See Abstract on page 23.
9. Riise, C. and Sheikholeslam, A. The influence of experimental interfering occlusal contacts on the activity of the anterior temporal and masseter muscles during mastication. J. Oral Rehabilitation, 11: 325-333, 1984. See Abstract on page 25.
10. Kydd, W. L., Choy, E. & Daly, C. Progressive jaw muscle fatigue and electromyogram activity produced by isometric unilateral biting. The Journal of Craniomandibular Practice, (4)1: 18-21, 1986. See Abstract on page 27.

SECTION 2: STUDIES THAT DOCUMENT THE RELATIONSHIP BETWEEN ELECTROMYOGRAPHY AND MUSCULAR FORCE

1. Lippold, O.C.J. The relation between integrated action potentials in a human muscle and its isometric tension. J. Physiol., 117: 492-499, 1952. See Abstract on page 28.
2. Bigland, B., and Lippold, O.C.J. The relation between force, velocity and integrated electrical activity in human muscles. J. Physiol., 123: 214-224, 1954. See Abstract on page 29.
3. Molin, C. Vertical isometric muscle forces of the mandible: A comparative study of subjects with and without manifest mandibular pain dysfunction syndrome. Acta Odont. Scand., 30: 485-499, 1972. See Abstract on page 30.
4. Milner-Brown, H.S. The relation between the surface electromyogram and muscular force. J. Physiol. 246: 549-569, 1975. See Abstract on page 31.
5. Pruim, G.J., Ten Bosch, J. J., and De Jongh, H. J. Jaw muscle EMG-activity and static loading of the mandible. J. Biomechanics, 11: 389-395, 1978. See Abstract on page 32.

SECTION 3: STUDIES THAT DOCUMENT THE REPRODUCIBILITY AND RELIABILITY OF SURFACE ELECTROMYOGRAPHY

1. Hermens, H.J., Boon, K.L., and Zilvold, G. The clinical use of surface EMG. *Medica Physica*, 9: 119-130, 1986. *See Abstract on page 33.*
2. Riise, C. Clinical and electromyographic studies on occlusion. From the Department of Stomatognathic Physiology, Karolinska Institutet, Stockholm, Sweden, pp. 20-21, 1983. *See Abstract on page 34.*
3. Goldensohn, E. Electromyography. From Disorders of the Temporomandibular Joint. Lazlo Schwartz, ed. W.B. Saunders Co., Philadelphia/London. pp. 163-176, 1966. *See Abstract on page 35.*
4. Lloyd, A.J. Surface electromyography during sustained isometric contractions, *J. Applied Physiology*, 30: 713-719, 1971. *See Abstract on page 36.*
5. Mitani, H., and Yamashita, A. On the power-spectra of the surface electromyograms of masticatory muscles. *J. of Osaka Dental Univ.*, 6: 1-12, 1978. *See Abstract on page 38.*
6. Burdette, B.H., and Gale, E.N. Intersession reliability of surface electromyography. *Journal of Dental Research*, Abstract No. 1370, Volume 66, 1987. *See Abstract on page 41.*

SECTION 4: STUDIES THAT DOCUMENT THE STATISTICAL COMPARISON OF QUANTITATIVE ELECTROMYOGRAPHY FROM THE MASTICATORY MUSCLES OF THE “PATIENT” POPULATION TO THAT OF THE “NORMAL” POPULATION

1. Moller, E. The chewing apparatus: An electromyographic study of the action of the muscles of mastication and its correlation to facial morphology. *Acta Physiologica Scandinavica*, Vol. 69, Supp. 280, 73-74, 1966. *See Abstract on page 42.*
2. Lous, I., Sheikholeslam, A., and Moller, E. Postural activity in subjects with functional disorders of the chewing apparatus. *Scand. J. Dent. Res.*, 78: 404- 410, 1970. *See Abstract on page 43.*
3. Moller, E. Sheikholeslam, A., and Lous, I. Deliberate relaxation of the temporal and masseter muscles in subjects with functional disorders of the chewing apparatus. *Scand. J. Dent. Res.*, 79: 478-482, 1971. *See Abstract on page 44.*
4. Sheikholeslam, A., Moller, E., and Lous, I. Pain, tenderness and strength of human mandibular elevators. *Scand. J. Dent. Res.* 88: 60-66, 1980. *See Abstract on page 45.*
5. Sheikholeslam, A., Moller, E., and Lous, I. Postural and maximal activity in elevators of mandible before and after treatment of functional disorders. *Scand. J. Dent. Res.*, 90: 37-46, 1982. *See Abstract on page 47.*
6. Moller, E., Sheikholeslam, A., and Lous, I. Response of elevator activity during mastication to treatment of functional disorders. *Scand. J. Dent. Res.*, 90: 37-46, 1984. *See Abstract on page 49.*
7. Cram, Jeffrey R, and Engstrom, David. Patterns of neuromuscular activity in pain and nonpain patients. *Clinical Biofeedback and Health*, Vol. 9, No.2, pp. 106-115, 1986. *See Abstract on page 50.*
8. Michler, L., Moller, E., & Bakke, M. On-line analysis of natural activity in muscles of mastication. *Journal of Craniomandibular Disorders: Facial & Oral Pain*, Vol. 2, No. 2: 65-82, 1988. *See Abstract on page 51.*
9. Gervais, R.O., Fitzsimmons, G.W., and Thomas, N.R. Masseter and temporalis electromyographic activity in asymptomatic, subclinical, and temporomandibular joint dysfunction patients. *The Journal of Craniomandibular Practice*, Vol. 7, No. 1, pp. 52 - 57, 1989. *See Abstract on page 52.*

SECTION 5: STUDIES THAT SUPPORT THE CLINICAL EFFICACY OF ELECTROMYOGRAPHY IN DENTISTRY.

1. Moller, E. Clinical electromyography in dentistry. *mt. Dent. J.*, 19: 250- 266, 1969. *See Abstract on page 54.*
2. Helkimo, E., Carlsson, G.E., and Carmeli, Y. Bite force in patients with functional disturbances of the masticatory system. *Journal of Oral Rehabilitation*, 2: 397-406, 1975. *See Abstract on page 56.*
3. Myslinski, N.R., Buxbaum, J.D., and Parente, F.J. The use of electromyography to quantify muscle pain. *Meth. and Find. Exptl. Clin. Pharmacol.*, 7(10): 551-556, 1985 *See Abstract on page 57.*
4. Riise, C., and Sheikholeslam, A. The influence of experimental interfering occlusal contacts on the postural activity of the anterior temporal and masseter muscles in young adults. *J. Oral Rehabilitation*, 9: 419-425, 1982. *See Abstract on page 21.*
5. Sheikholeslam, A., and Riise, C. Influence of experimental interfering occlusal contacts on the activity of the anterior temporal and masseter muscles during submaximal and maximal bite in the intercuspatal position. *J. Oral Rehabilitation*, 10: 207-214, 1983. *See Abstract on page 23.*
6. Riise, C., and Sheikholeslam, A. The influence of experimental interfering occlusal contacts on the activity of the anterior temporal and masseter muscles during mastication. *J. Oral Rehabilitation*, 11: 325-333, 1984. *See Abstract on page 25.*
7. Pantaleo, T., Prayer-Galletti, F., Pini-Prato, G., and Prayer-Galletti, S. An electromyographic study in patients with myofascial pain-dysfunction syndrome, *Bulletin Group. Int. Rech. sc. Stomat. et Odont.*, 26: 167-179, 1983. *See Abstract on page 59.*
8. Cooper, B. C., Alleva, M., Cooper, D., & Lucente, F. E. Myofascial pain dysfunction: Analysis of 476 patients. *Laryngoscope*, 96: 1099-1106, 1986. *See Abstract on page 61.*
9. Sheikholeslam, A., Holmgren, K. & Riise, C. A clinical and electromyographic study of the long-term effects of an occlusal splint on the temporal and masseter muscles in patients with functional disorders and nocturnal bruxism. *Journal of Oral Rehabilitation*, 13: 137-145, 1986. *See Abstract on page 63.*

**STUDIES THAT DOCUMENT THE PHYSIOLOGICAL BASIS FOR THE
EFFICACY OF ELECTROMYOGRAPHY IN DENTISTRY**

In a thorough review of the EMG literature in 1963, Vig concluded that “orthodontic appliance technology is well in advance of our understanding of the physiological basis of occlusal dysfunction. By methods such as electromyography, a sounder approach, with the elimination of some futile treatment procedures leading to disappointing results and relapses, may be expected.”

Vig, P. Electromyography in dental science: A review. Australian Dental Journal, pp. 315-322, August, 1963.

INTRODUCTION

Electromyography is not a new field of study - - references in scientific literature date back to 1908 (Buchanan). However, it was not until 1949 when Moyers (1949, 1950) initially applied this technique to a study of the musculature related to the temporomandibular joint, that dental research discovered this versatile tool.

PHYSIOLOGICAL BASIS

Skeletal muscle activity is controlled by efferent nervous impulses, mediated either at a segmental reflex level or modified by cortical control, as is the case in the more complexly coordinated movements required to maintain posture and function of the masticatory system. The nature of cortical activity is modified by both conscious control and the afferent sensory and proprioceptive messages relayed from the periphery.

Generally, larger motor units are found in the muscles which perform slow, sustained contractions, while the smaller motor units are found where rapid, non- sustained tension is required for finely coordinated movements. The innervation ratio, i.e., the proportion of muscle fibres to the motor neurones in the central nervous system, in the motor neurone pool varies over a wide range, from the order of 300:1 as found in the gluteus maximus, to as low as 3:1 in the extrinsic musculature of the eye.

The innervation ratios of the muscles of mastication have not been accurately determined, although electromyographic results suggest values of 110:1 for the masseter and 200:1 for the temporalis muscles (Wyke, 1949). Knowledge of this property is important as theoretically the smallest increment of contraction is due to the additional recruitment of a single motor unit.

When the nervous impulse reaches the resting mass of protoplasm, ions, and water, it adopts the functional posture which we usually associate with muscle (Perry, 1955). Concomitant with this, there are several changes such as development of tension, a shift in mass, production of metabolites and heat, as well as minute electrical changes of the order of microvolts.

THE METHOD

Electromyography has evolved from the now well-established techniques of electrocardiography and electroencephalography. The essentials of the equipment required are:

- (1) The electrodes- -which pick up the minute electrical activity.
- (2) An amplifying system to magnify these signals.
- (3) A means of recording the amplified signals.

THE ELECTRODES:

There are basically two types of electrode in common use:

- (a) The surface electrode consisting of a small metal disc attached to the skin over the muscle by a suitable conducting material such as celloidin.
- (b) The needle electrode which consists of a small bore hypodermic needle, containing an insulated wire.

Surface electrodes are therefore suitable for the study of integrated activity of the muscle mass immediately beneath them. By suitable, symmetrical placement of these electrodes over paired muscles, their relative activity may be studied at rest and in various movements

What then are the uses of electromyography?

Electromyography has contributed by affording a method of studying the physiological basis of function of such vital activities as mastication, deglutition, and speech. Furthermore, electromyography and cineradiography are the only methods of observing dynamically these activities. By understanding the normal we can base treatment on a rational level and eliminate empiricism from our clinical assessments

Perry (1949, 1950) used cephalometric monitoring of the electromyographs coupled with sound units. Identical tracings were repeatedly obtained from roentgenograms taken at the silent audio positions in nearly all cases. In his two cases where audio silence could not be obtained, he found a level of activity persisting in the temporalis muscle. On clinical examination, these patients were found to suffer from occlusal disturbances and temporomandibular joint symptoms. Following correction of these conditions, audio silence and cephalometrically reproducible rest position were obtained.

Schpuntoff and Schpuntoff found that general posture, pain, fatigue, and central nervous system excitation were major factors affecting the establishment of a physiological rest position (1956)

Jarabak (1957) recorded "electrical silence" from the elevators (masseter, temporalis) and a depressor (digastric) at rest position. In edentulous patients, with dentures operating through an excessive interocclusal clearance (i.e., between 8-12 mm.), he found spontaneous activity at rest, both in the temporalis and digastric muscle.

Recordings from the perioral and suprahyoid musculature by Schlossberg also showed minimal activity at rest (Franks, 1957).

RELATION OF ELECTROMYOGRAPHY TO CLINICAL PROBLEMS

OCCLUSAL REHABILITATION:

Minor discrepancies in a single occlusal restoration can produce alteration from a bilaterally balanced to an asymmetrical muscular contraction pattern (Porritt, 1960). This can inhibit normal function and result in altered occlusal patterns.

In denture prosthesis the assessment of the rest position is of prime importance. The numerous clinical methods used to record it, attest to the empirical nature of this procedure.

Electromyography has been used to obtain reproducible records of the rest position (Schpuntoff & Schpuntoff, 1956) and it has been suggested that electromyographic comparison of the various maneuvers should be undertaken to assess their reliability and accuracy

TEMPOROMANDIBULAR JOINT DYSFUNCTION

Cases suffering from temporomandibular joint dysfunction with atypical pain patterns are frequently a source of frustration to both dentist and patient. Many of these apparently atypical neuralgias have previously been wrongly ascribed to psychogenic causes.

Perry (1955) has shown that many of these pains are due to muscle spasms in the masseters, pterygoids, and temporalis muscles. With the establishment of more physiological jaw relations, the electromyograms show a reduction of these muscle spasms with relief of pain.

Grossman (1961) reported on joint disorders where clinical deviations occasioned by premature cuspal contacts in malocclusions, produced characteristic myograms.

Correction of the malocclusion resulted in symmetrical function and resolution of the joint symptoms ...

This early EMG study by Jarabak (1956) suggests many clinical possibilities for evaluating the relationship between occlusion, the temporomandibular joint and the muscles of the mandible. The findings of Jarabak, as will be demonstrated in this report, have been confirmed by numerous studies in the past 30 years.

Jarabak, J.R. An electromyographic analysis of muscular and temporomandibular joint disturbances due to imbalances in occlusion. *Angle Orthodont.*, (26)3: 170-190, 1956.

Functional disorders of the temporomandibular joint characterized by clicking, crepitus, trismus and pain are sufficiently prevalent to warrant physiological analysis. Muscles surrounding a joint, and responsible for its movements, frequently go into a state of hyperactivity or spasmodic contraction when this joint becomes painful.

This study was designed to serve a threefold purpose, the first of which was to determine whether or not occlusal interferences cause functional imbalances in the temporal muscles. Second, if so, are these imbalances a contributing factor to clicking, trismus and pain in the temporomandibular joint? Third, is it possible to eliminate abnormal muscular activity by re-establishing a correct functional occlusion?

Records of neuromuscular activity from the temporal muscles of biting, rest after biting, and rest after speaking, were taken from three groups of patients. In the first group were subjects with good occlusions who were free from temporomandibular joint symptoms. In the second were orthodontic patients who had a clicking or who had developed a clicking in the joint during reduction of a distal occlusion with intermaxillary elastics. The third group were patients with functionally broken down occlusions accompanied by clicking, pain and trismus in the temporomandibular joint. Many of these subjects had, in addition to pain in the joint, deep pain in some of the muscles used in mandibular posture.

METHODOLOGY

MATERIALS

From three groups of subjects, neuromuscular activity from the temporal muscles was electromyographically studied. In the first group were four patients, in the second, seven, and in the third, eleven.

The subjects with normal occlusion had fourteen teeth in each arch and there had been no previous extraction. None had signs of clicking, crepitus or pain in either temporomandibular joint.

Three of the seven orthodontic patients in the second group had clicking in the point before orthodontic treatment was started; the remaining four developed a resounding click shortly after intermaxillary elastics were placed to reduce a distal occlusion.

The third group were adult subjects. All had at some time or another lost posterior teeth.

FINDINGS

I. Neuromuscular activity from a subject with normal occlusion free from joint disturbance.

A typical rest record (Figure 3), taken from a control subject . . . shows no appreciable neuromuscular activity.

II. Neuromuscular activity from a subject in orthodontic treatment.

At a point in the reduction of a distocclusion with intermaxillary elastics some orthodontic patients develop a resounding clicking in . . . temporomandibular joints. Electromyograms shown in Figure 4 indicate that a spontaneous hyperactivity of a short duration occurs in the posterior fibers of the temporal muscle.

This spontaneous hyperactivity is seen during rest after biting and in rest after speaking.

III. Neuromuscular activity from adult non-orthodontic subjects who have gross occlusal interferences.

In rest after speaking, as in rest after biting, spontaneous hyperactivity continues (Figure 6). At times it is greater than at other times. Generally, when it is greater these patients complain of a deeply seated radiating pain over the area of the temporal muscle. Seemingly, these muscles do not come to rest for long periods of time during these spasm seizures.

IV. Neuromuscular activity after placement of interocclusal splint.

Spasms in the temporal muscle have already been observed when pain is present in the temporomandibular joint.

Thus, electromyographic data of neuromuscular activity seem to substantiate the premise that functional occlusal interferences, coupled with temporomandibular joint clicking and pain, occur concurrently with muscle spasms. When the occlusal interferences were removed in this group with interocclusal splints, spasms disappeared.

V. Neuromuscular activity after interocclusal splint was removed.

To further illustrate that a correct occlusion or one free from occlusal interferences is an important link in the chain of events leading to proper neuromuscular balance in the temporal muscles, let us consider what occurs when the interocclusal splint is removed. Its removal permits the teeth to return to their original occlusion beset with functional occlusal interferences.

Electromyograms shown in Figure 9 were taken approximately five minutes after the splint was removed. Rest activity after biting (Figure 9) clearly illustrates that spontaneous hyperactivity returns as an immediate after-discharge following the voluntary motor activity. If this hyperactivity - - the spasm -• is compared with that from this subject, for the same exercise, before the interocclusal splint was inserted, it appears nearly identical. Upon removal of the splint the temporal muscles were thrown once again into a functional imbalance; spasms occur in the muscle and clicking returns to the temporomandibular joint.

DISCUSSION

The temporal muscle, by virtue of its origin from the side of the cranium and its insertion to the coronoid process of the mandible, has the function of elevating the mandible. (Although) its prime activity is to elevate the mandible, it also has several ancillary functions.

In order to have the myriad of complex movements associated with chewing and swallowing rhythmic and smooth, it is necessary to have muscle activity precisely timed and synchronously carried out by some muscles which are contracting, by others which are relaxing, and by still others which are holding, guiding or poising the mandible. It is the integrated action of several muscles or muscle groups acting in unison through a precise timing of nerve impulses from the central nervous system which makes coordinated muscle activity possible. Thus the mandible is a human lever whose movements in speaking, and at rest, and in chewing, and in swallowing, are neuromuscularly controlled.

If any member in this community of muscles falters or becomes sick, it is logical to assume that its activity may alter the activity of the remaining members of the group and may in this manner affect the joint whose movements they control. Since a precise starting and stopping equilibrium (reciprocal innervation) exists between antagonistically acting muscles, it is possible to visualize how a muscle spasm in the temporal muscle may disrupt or change the timing sufficiently to throw their antagonists, the lateral pterygoid and the digastric muscles, out of a contraction and relaxation sequence.

The spontaneous hyperactivity in the temporal muscle occurring as a result of orthodontic treatment was quite revealing because it pointed out that stimuli originating in the teeth can make a muscle spastic where spasticity did not previously exist. It also brought out the significant fact that these tooth stimuli manifest their effects on patterns of muscular activity only when the teeth in the upper arch are in a certain position to the teeth in the lower arch. Spontaneous hyperactivity occurred when the teeth formerly in distocclusion were placed into a cusp-to-cusp occlusion. As a result of this position of the teeth in their respective arches, it was possible for the mandible to slide either forward or backward. It was during this period of backward and forward sliding that a resounding clicking developed in the temporomandibular joint. It was also at this time that the spontaneous hyperactivity occurred in the posterior fibers of the temporal muscles.

As soon as the teeth began occluding in a normal occlusal relation the clicking diminished, but did not disappear completely until the occlusion had functionally equilibrated itself, or until it was equilibrated. Thus the mere reduction of a distocclusion is not tantamount to a balanced muscular activity. This comes only when the denture has functionally equilibrated itself or when it is equilibrated

The method (interocclusal splint) used to control muscle spasms in the temporal muscle leaves very little doubt that occlusion and the maintenance of correct vertical dimension between the maxilla and the mandible are important factors in the physiology of the temporomandibular joint. Let us consider some of the sources of sensory stimuli which may cause muscular imbalance, an imbalance which may in turn cause joint pain, clicking and trismus.

If an adverse stimulus is short in duration, that is, if the patient can remove the occlusal interference in night grinding, or if it is removed by the dentist by equilibrating the occlusion, the musculature returns to its normal activity. If, on the other hand, a cuspal interference persists or if multiple interferences develop and adverse stimuli continue to be imposed, reflexly, upon the muscles, it is possible to visualize the development of muscular confusion muscle spasms.

Duchene (1867) observed that muscles surrounding a joint would go into a state of hypertonus when the joint was inflamed, injured or dislocated. In severe dislocations the muscles might even go into a "state of spasmodic contraction." Though muscle spasms can be initiated reflexly in the periodontium of the teeth, they can also come from the sensory stimuli having their origin in the capsule of the joint.

The electromyograms in Figure 7 show that, when occlusal interferences were removed and correct vertical dimension was restored with an interocclusal splint, muscle spasms disappeared. This immediate change from muscle spasm to one of normal muscle activity indicates, in the light of our present evidence, the basic etiology for these spasms to lie in cuspal interferences of the teeth. Because these spasms disappeared almost immediately with the placement of the splint, it is difficult to visualize, if the cause for the spasms was inflammation of the capsule, how this inflammation could be spontaneously eliminated. For the present, experimental evidence leans in the direction of placing the cause for muscle spasms in the temporal muscle to occlusal interferences rather than on inflammation in the temporomandibular joint

SUMMARY

Electromyographically it is possible to show that muscle spasms occur in the two fractions of the temporal muscles. These spasms were found in orthodontically treated and in non-orthodontic subjects. In the orthodontically treated as well as in the non-orthodontic patients, spasms were present when clicking, trismus and pain occurred in the temporomandibular joint. In the orthodontic subjects who had developed a clicking during treatment, the hyperactivity was not as great and as frequent as it was in the non-orthodontic patients who had clicking, trismus and pain for a long period. The severity and duration of spasms depend on the length of time and degree of impact arising from interocclusal interferences. In orthodontic subjects adverse proprioceptive stimuli arising from an end to end occlusion of cusps were of short duration, provoking only mild spontaneous hyperactivity. Where the adverse stimuli arising from multiple cuspal interferences were of long duration, muscular hyperactivity was greater and lasted for longer periods. In the latter, muscle spasms were distinctly concurrent with clicking, trismus and pain in the temporomandibular joint.

Because spasms in the temporal muscles were eliminated with an interocclusal splint in subjects who had gross occlusal interferences and an excessive interocclusal space, and because these spasms re-occurred almost immediately on removal of the splint, the etiology for muscle spasms in the temporal muscles is attributed to occlusal interferences and an excessive interocclusal space. This does not mean that other factors cannot cause temporal muscle spasms.

CONCLUSIONS

1. The behavior of skeletal muscle is a faithful index of the state of the motor nerve center (lower motor neurone).
2. Temporal muscle spasms occur simultaneously with functional disturbances in the temporomandibular joint.
3. Functional disturbances in the temporomandibular joint may have their etiology in occlusal interferences of the teeth.
4. Muscle spasms disappear in the temporal muscles when occlusal interferences were removed (in our subjects with an interocclusal splint).
5. Upon removal of the splint, muscle spasms re-occurred in the right temporal muscle.
6. Deeply seated muscle pains are very likely due to physiochemical changes in the spastic muscle.

This 1954 study by Perry & Harris at Northwestern University Dental School documented the significance of EMG in providing a physiologically valid occlusion. According to Perry the placement of dental restorations which are not perfectly adapted to the existing patterns of parts and their functional movements will cause pounding of the tooth and its restoration through the action of resisting oral musculature during occlusion.

Perry, H.T. and Harris, S.C. Role of the neuromuscular system in functional activity of the mandible. Journal of Am. Dent. Assoc., 48: 665-673, 1954.

Most anatomy books assign a particular function to each muscle, but they do not point out that each muscle may have many other functions as well. For instance, all muscles attached to the mandible have some active part in mastication, either in contracting or in relaxing. The contribution of muscle to oral activity is governed by the architecture of the jaw and muscle attachment, by occlusal relations of the teeth, by the demands of various types of food and by the innate or acquired functional pattern of the individual.

The placement of dental restorations which are not perfectly adapted to the existing pattern of parts and their functional movements will cause pounding of the tooth and its restoration through the action of the resisting oral musculature during occlusion. This pounding will continue until the units are thrust aside, the functional pattern is changed, or the parts are lost. In the words of Todd, "Mechanically, physiologically, and psychologically, the human body is compelled to struggle for a state of equilibrium." (1937).

Application of these principles and equipment has demonstrated that structural differences, such as malocclusions (Moyers, 1950), pathologic conditions of nervous or muscular origin (Pruzansky, 1952) and the alteration of individual tooth position (Perry, 1954), produce distinctive results on myograms.

The electromyograms of Figures 1, 2, and 3 show the mastication patterns of a patient with normal occlusion; they were taken in immediate sequence and reveal the following features: (1) the relation of the pairs of masseter and temporal muscles to each other in extent and time of activity, (2) the occurrence of greater activity on the working side in mastication, (3) the qualitative uniformity of activity when a response is repeated and (4) the gradation and extent of activity with increasing load

INTERPRETATION OF MYOGRAMS

This instrument and technique were used to obtain myograms of the action of the masseter and temporal muscles of ten patients with cephalometrically and anatomically normal occlusion. The myograms, of which Figures 6 and 7 are typical, revealed the following characteristics of muscular action during the chewing of gum:

- [1] As they reached maximal activity, the temporal and masseter muscles on both sides were synchronized.
- [2] The temporal muscles always displayed electrical activity before the masseter muscles went into action.
- [3] There was more harmony and smoothness of action-potential discharge on the side preferred for mastication.
- [4] The amplitude of the myogram was in direct proportion to the resistance of the bolus being chewed.

Myograms may prove of clinical value. The following typical characteristics were observed in Class II division I malocclusions (Fig. 8 and 9).

- [1] The temporal and masseter muscles on both sides reached maximal activity asynchronously.
- [2] The masseter muscles frequently were first to manifest electrical activity.
- [3] There was much less harmony and virtually no smoothness of action-potential discharge on both sides, although there was less disharmony on the preferred side.

It may be concluded that muscle has the dominating role in mastication, supplying function and resisting any degree of mechanical disharmony. The evidence, already abundant, is corroborated by electromyograms.

Figure 10, for example, is an electromyogram of the right side of the same subject shown in Figure 6. The occlusal condition of this patient was declared normal by six orthodontists who did not use electromyography in their diagnosis. The electromyograph, however, revealed that something was wrong; by further examination of the study models and of the mouth, it was found that the upper right third molar was in premature contact.

CONCLUSION

Many neuromuscular phenomena are not yet understood; future research in neuromuscular physiology will unquestionably be of great assistance in the solution of clinical problems. In the meantime, the dentist must recognize that all force in the oral cavity is produced by muscle. The number, origin and insertion of fibers and their innervation are established genetically. These are the structures most resistant to change in the entire body. Therefore, the best means of helping the patient is to restore or maintain the normal physiology of the mouth, seeking to cooperate with these structures rather than causing them to resist and to produce pathologic conditions.

More than 30 years ago, Perry at Northwestern University monitored the postural EMG activity of patients with temporomandibular disorders before and after treatment. Electromyographic evidence of spasm at rest was observed before treatment, he concluded that patients who were treated by occlusal splinting demonstrated substantially lower or non-existent postural activity after treatment.

Perry, H. T. Muscular changes associated with temporomandibular joint dysfunction. *Journal of Am. Dent. Res.*, 54: 644-653, 1957.

Too often in their endeavors to restore oral health, dentists are oblivious of the whole patient and direct their efforts to special dental problems, the placement of a single inlay or bridge, or the orthodontic correction of the teeth into an acceptable anatomic arrangement.

In the dentist's efforts to establish anatomic normalcy, he often forgets the principles of physiology - - "how" and "why" all of these various parts are anatomically interrelated to achieve function. Too often knowledge of basic science is eclipsed by the pragmatism of office efficiency. This shortsightedness results in a neglected service to the total needs of the patient.

Dentistry has made great strides in the fields of dental materials, improved cutting methods, local anesthetics, control of dental decay and oral rehabilitation; in short, the dentist can well manage the structures he sees. A certain percentage of patients, however, present themselves with problems of pain, malaise and poorly defined complaints of discomfort. The suffering some of these patients have endured and the future pain they may suffer when they leave the dentist's office without an attempt by the dentist to help them may not be realized. Often the patients are conveniently classified as neurotics.

The orthodontic department of Northwestern University Dental School has long been concerned with functional problems of the occlusion and temporomandibular joints. Research studies by graduate students have been designed to enlarge the scope of understanding of the anatomy, physiology and pathology of this joint.

The electromyograph has supplied another useful adjunct in studying functional problems. When used in conjunction with the cephalometric roentgenogram and a careful clinical examination, many interesting features of oral function have been more thoroughly studied than was previously possible. A great deal of the material in this report is based on electromyographic findings of the past four years.

The material presented in this paper is derived from 42 patients treated at the Northwestern University orthodontic department's temporomandibular joint clinic. The number of patients treated and observed in this special clinic exceeds this number many times; however, each one of these 42 patients had one or more electromyographic examinations. Another 84 instances were taken from the private practice of J. R. Thompson, because of the completeness of his records. A few of the latter patients had also been investigated with the electromyograph. The total number of patients studied was 126.

Models, cephalometric and intraoral roentgenograms, functional wax records (Thompson, 1954), pain distribution charts and complete functional examinations were obtained in each instance. Electromyographic records were taken in many instances. Tape recordings of the patient describing the subjective nature and distribution of the pain were taken of the clinic patients. In certain instances it was also desirable to examine the head of the condyloid process with temporomandibular joint roentgenograms by using the Donovan modification of the Lindblom apparatus.

PATTERN OF PAIN

Utilization of electromyographic examination in diagnosis permits an evaluation of possible involvement of muscle as related to pain. All of the patients studied in the clinic were examined electromyographically during treatment and also after the corrective treatment was administered.

When a healthy, normally innervated, voluntary muscle is at rest, there are no signs of activity recorded by surface electrodes (Hofer, 1949). Should the slightest movement occur or the least bit of contraction take place, however, electrical discharges are "picked up" by the surface electrodes.

THE RESTING MUSCLE

When a muscle is at rest a small amount of energy is expended in maintaining a slight tension, referred to as "tonus." Tonus is like a "continual alertness" which keeps the muscle constantly prepared to act. The activity of tonus is maintained by a few widely separated and deeply located motor units. With surface electrodes this electrical activity is not recorded, because only a few motor units are randomly active in dispersed regions within the entire muscle.

Therefore, a healthy resting muscle displays no evidence of innervation recordable by surface electrode and an electromyographic record from one of these resting muscles shows only a straight base line when the amplification level is set at a gain of 4 as was used in these studies.

In patients with occlusal disharmonies and temporomandibular joint dysfunctions, the absence of a true electromyographic resting pattern from the muscles of mastication has been noted. The temporal and masseter muscles, when more severe dysfunction is present, constantly exhibit a low grade electrical discharge even when the mandible is supposedly in the physiologic rest position. Certain findings with needle electrodes indicate that this is also true for the external and internal pterygoid muscles. This sustained electrical discharge and absence of rest is characteristic of muscle spasm which is due to an overactive neural discharge.

In all of the patients studied electromyographically, the pattern of muscle spasm closely followed the topographic distribution of subjectively recognized pain. This finding presented a definite basis for the dull, aching type of pain which was so characteristic in these patients.

In many of the earlier patients in the clinic it was noted that with the correction of the occlusal problems and the cessation of the temporomandibular symptoms of clicking, crepitus and pain, the electromyogram of the resting muscle no longer showed the electrical evidence of spasm. In other words, the "resting" muscles which had previously showed a spasm activity of electrical discharge, after treatment caused no base-line deflection of the pens and resembled a healthy electromyographic pattern of resting muscle. This seemed, in itself, some basis for assuming that the pain was related directly to the dysfunction. The cause and the effect seemed present but between there must be a connecting link. This was to be found in the realms of anatomy and physiology.

NEUROANATOMIC BASIS OF MANDIBULAR MOVEMENT

In those patients possessing only minor premature contacts or few occlusal irregularities, adjustment occurs as a normal process when occlusal conditions present many severe functional interferences in mandibular movements; however, the inconstancy and irregularity of the stimuli accompanying function produce a continual bombardment within the mesencephalic nucleus. This constant discharge of sensory impulses is relayed to synapses in the motor nucleus with the motor cells of the trigeminal nerve. The impulses then travel peripherally in the motor nerves to the muscles responsible for mandibular guidance and posture. The various components of each muscle attempt to guide the mandible into occlusal positions of least interference. In time a position of occlusion may be found at which the protective stimuli are minimal. Then the musculature strives to relocate this position with each occluding movement. This position of least occlusal interference is found and maintained at the expense of normal muscle function.

The musculature as a result of the continual overwork and guidance becomes fatigued and metabolic products accumulate. With these metabolic products the sensory endings for pain in these muscles are finally stimulated and a conscious recognition of localized pain results.

In the clinical treatment of these patients by occlusal splinting or occlusal equilibration in which interfering restoration or tooth structure is removed, the musculature is again permitted to carry out its action unhindered by excessive protective impulses. This is readily proved by the electromyographic recordings on occlusal and temporomandibular joints after correction. A few days after occlusal relief, the spasm in rest position is diminished, and in a week, if all premature contacts are relieved, the spasm and pain are gone and the rest position becomes constant.

In these instances wherein the proprioceptive stimuli of a poor occlusion constantly signal the mandibular musculature to find and maintain a position of least interference there is little opportunity for division of labor. With reflex guidance of the mandible fatigue in one segment of a muscle or muscle group is soon apparent.

This resulting fatigue eventually sets up the afore-mentioned spasm activity electromyographically noted at rest. With this slight degree of muscle contraction at rest, the posture of the mandible is upset. A true physiological rest position of the mandible no longer exists. The body, however, attempts to compensate for this imbalance by calling into action its second line of muscular reserves. Just as increased load values on one side of the body results in contraction of other distant balancing muscles, so do the postural and functional disturbances of the mandibular musculature. In this action the postcervical muscles are called into play in a distant attempt to establish balance in the function of the masticatory muscles.

This assisting role by certain of the postcervical muscles may result in temporary relief to the mandibular musculature. If, however, the offending parts of the occlusion are not corrected, the mandibular musculature and postcervical musculature (or parts of each) will soon present signs of over work, fatigue, spasm and pain. .

RESULTS OF TREATMENT

In 118 of the 126 patients in this study the pain was relieved by either occlusal equilibration or occlusal splinting. The remaining eight patients were relieved of some of the pain but have not, as yet, been completely relieved. In every instance wherein electromyographic evidence of spasm at rest was noted before treatment, the final electromyogram indicated a near normal or normal picture of rest that is, an absence of electrical activity at rest.

Yemm at the University of Bristol in England presents a neurophysiologic overview of temporomandibular joint dysfunction that supports many of the clinical neuromuscular protocols and their underlying neuromuscular basis. After an extensive review of the literature, and studying the EMG of a group of normal subjects and a group of dysfunctional patients, Yemm concludes, "There is an increasing weight of evidence that hyperactivity of jaw closing muscles may originate in the central nervous system. It is concluded that such centrally induced activity may be sufficient to cause muscle damage, which leads to disturbed function, local pain and tenderness and to pain referred to adjacent structures. The results demonstrate a clear difference between [the EMG of] the normal group and the patient group."

Yemm, R. Neurophysiologic studies of temporomandibular joint dysfunction. *Oral Sci. Rev.*, 7: 31-53, 1976.

INTRODUCTION

The clinical condition now commonly known as temporomandibular joint dysfunction was described, and interest aroused in it as a clinical entity, by the work of Costen, whose first report was published in 1934. It was considered at this time that the cause was pressure of the mandibular condyle upon related structures such as nerves, permitted by overclosure of the mouth. The overclosure hypothesis has since given way to the concept that other defects in the dental occlusion are the primary cause. More recently still, the emphasis has been changing once again, this time to the consideration of abnormalities of muscle and muscle activity as being responsible.

The purpose of the present paper is to review the neurophysiological evidence in favor of these hypotheses.

EVIDENCE THAT MUSCLE HYPERACTIVITY CAN CAUSE DYSFUNCTION

As Costen's ideas have been questioned, and generally found unacceptable, alternative hypotheses have been advanced. Two fundamentally different suggestions have been made. The first is that defects in the dental occlusion initiate or necessitate sufficiently abnormal muscle activity to cause dysfunction. The second, and more recent, is that muscle hyperactivity, not necessarily in the presence of occlusal abnormality, is the primary factor.

Common to both hypotheses is the concept that the dysfunction condition arises from hyperactivity of one or more of the jaw muscles. It is reasonable to examine the validity of this argument, without for the moment considering the cause of the hyperactivity.

A frequent clinical observation has been that many patients with temporomandibular joint dysfunction exhibit a tendency to clench or grind their teeth (e.g. Franks, 1965, Weinberg, 1974). Such observations are of necessity subjective, depending upon both the patient's awareness and upon the clinician's definition of what constitutes abnormality. Nevertheless it is proposed that this hyperactivity initiates and maintains the clinical condition. The validity of the clinical impression has been tested by Vestergaard Christensen (1967, 1971).

In two studies, normal adult subjects were asked to grind their teeth for a period of 30 minutes. Obviously, such voluntary hyperactivity has a different origin from that of the nocturnal, unconscious tooth grinding of bruxism, but it is reasonable to assume that its effects upon the system might be similar. All but one of Vestergaard Christensen's subjects in the later experiments experienced pain or discomfort in the period of time following the voluntary hyperactivity. The site, nature and duration of the symptoms described varied from subject to subject. His results are summarized in Fig. 1. The distribution of pain sites seems very similar to the varied reports of patients with temporomandibular dysfunction. The relatively short duration of the experimentally induced signs and symptoms is obviously different from that seen in the majority of patients. However, the hypothesis demands that the dysfunction patient be a habitual tooth clencher or grinder, and a limited duration of pain would be expected following a single relatively brief period of hyperactivity.

This evidence constitutes the main experimental support for the clinical contention that dysfunction is caused by muscle hyperactivity. Studies of the muscle activity of dysfunction patients, the majority employing electromyographic techniques, are less conclusive, since in many it is not possible to determine whether any demonstrated hyperactivity is causative or a consequence of the dysfunction. Reports of this nature will be considered in a later section.

The suggestion that muscle hyperactivity can lead to muscle pain is not limited to jaw muscles. Swanson (1971) considers that muscle pain with this origin is common. Examples quoted are occupational muscle pain in typists and writers. In addition Wolf (1972) has discussed the involvement of muscle hyperactivity and muscle pain in some types of headache.

EVIDENCE OF CENTRALLY INITIATED HYPERACTIVITY

The absence of scientific support for the theory that temporomandibular joint dysfunction is due to hyperactivity initiated by occlusal defects has led, together with observations of the type of patient most often subject to dysfunction, to the proposal by numerous authors that hyperactivity of the jaw muscle originates centrally in the nervous system (e.g. Copland, 1954, Kydd, 1959, Franks, 1965, Berry, 1967, Newton, 1969, Weinberg, 1974). It is suggested that psychological or physical stress experienced by the individual leads to an increase in muscle activity of the jaw muscles, and that this contributes to, if not actually causes, the onset and maintenance of dysfunction.

The phenomenon of increased muscle tension in the human under stress is well documented. Increases in activity of a number of muscles have been shown to occur during both mental and physical stress. For instance Malmö and Shagass (1949) showed increases in activity of some neck muscles when radiant heat was applied to the forehead. Goldstein and co-workers (Goldstein et al, 1964, Shipman et al, 1964, Goldstein, 1965) have shown that activity of several muscles, including biceps, frontalis, trapezius and some neck muscles, can increase during interviews by a psychiatrist, the response being dependent upon the character of the interview.

Using the method of inducing stress already described, which permits repeated exposure within one experimental session, three groups of subjects were examined. The first group was composed of ten normal subjects, the second of ten dysfunction patients, and the third of ten subjects for whom treatment of dysfunction had been completed. The three groups, who were matched as far as possible for age and sex distribution, provided a means of testing whether any difference detected between normal subjects and patients was also present when the clinical condition had been resolved. As in the previously described studies of stress induced activity in normal subjects, electromyography was used to determine muscle activity changes. The signals were tape recorded for subsequent analysis using integration.

In each of the 30 subjects tested, recording of muscle activity was carried out for one masseter muscle for four attempts at the task. A brief rest was permitted between each two minute exposure to the task. At the time of testing, several of the dysfunction group exhibited tenderness of one masseter, in which case the recordings were taken from the clinically normal contralateral muscle. Each subject was given a short practice period, and no mention was made of the fact that the surface electrodes were sampling muscle activity.

The results demonstrate a clear difference between the normal group and the patient group. The latter consistently failed to demonstrate the progressive relaxation shown by the normal subjects. Fig. 7 is a typical individual response from the patient group for comparison with that of a normal subject (Fig. 6). Of the subjects with a previous history of dysfunction, only three showed any evidence of a progressive reduction in response. The responses of the three groups are shown in Fig. 8.

A number of reports have been made to the effect that the jaw muscles of temporomandibular joint dysfunction patients are hyperactive. In some instances it is reported that this activity is continuous, and considered to be a feature of the clinical condition (Jarabak, 1956, Perry, 1957, Griffin and Munro, 1971, Chaco, 1973). Others indicate the hyperactivity diminishes at times when, in the light of the observations of stress induced muscle activity, the patient is encouraged or permitted to relax (Kydd, 1959, Franks, 1965, Moller et al, 1971). Some of these studies are without control samples of normal subjects; the implication of some that muscle hyperactivity is characteristic of the jaw closing muscles in dysfunction patients will be examined in a subsequent section.

THE ACQUIRED PATHOLOGY

Recognizing the frequent muscle involvement in the generation of the signs and symptoms observed, it has been suggested that the problem is one of muscle spasm. Spasm of skeletal muscle is usually defined as uncontrolled muscle contraction of a brief or maintained character (Rushworth, 1961). The existence of muscle spasm in the jaw muscles of patients with dysfunction is suggested by a number of authors.

Travell (1960) considers that the spasm arises from trigger areas within the affected muscle, stimulation of which results in maintained activity. Several studies have advanced evidence that continuous activity, claimed to be spasm, is a feature of the muscles of dysfunction patients (Jarabak, 1956, Perry, 1957, Griffin and Munro, 1971, Chaco, 1973). However, others report that although hyperactivity was observed, this reduces if the patient is permitted or encouraged to relax (Kydd, 1959, Franks, 1965, Moller et al, 1971, Yemm, unpublished observations). The presence of continuous, spastic activity in the jaw muscles must be considered doubtful, therefore.

Evidence suggesting that continuous spasm is unlikely to exist is provided by studies of jaw movements. A frequent feature of dysfunction is the existence of a restriction of mouth opening or trismus.

SUMMARY

There is an increasing weight of evidence that hyperactivity of jaw closing muscles may originate in the central nervous system. It is concluded that such centrally induced activity may be sufficient to cause muscle damage, which leads to disturbed function, local pain and tenderness and to pain referred to adjacent structures.

The influence of afferent proprioceptive input from occlusion causes an asymmetry of muscle activity according to Bakke and Moller. Bilateral bipolar surface electrodes were the mode of choice. The authors, in a study at Royal Dental College in Copenhagen, demonstrated that "biting in the intercuspal position with unilateral premature tooth contact causes asymmetry of the elevators, with strongest activity on the side of interference" and "a reduction of mean voltage on both sides with increasing height of the overlay (prematurity)".

Bakke, M., & Moller, E. Distortion of maximal elevator activity by unilateral premature tooth contact. Scand. J. Dent. Res., 80: 67-75, 1980.

In four subjects the electrical activity in the anterior and posterior temporal masseter muscles during maximal bite was recorded bilaterally with and without premature unilateral contact. Muscle activity was measured as the average level and the peak of the mean voltage with layers of strips of 0.05, 0.10, 0.15 and 0.20 mm, placed between first molars either on the left or the right side, and compared with the level activity with undisturbed occlusion. Unilateral premature contact caused a significant asymmetry of action in all muscles under study with stronger activity ipsilaterally. With increasing thickness of the overlay, the mean voltage decreased in parallel on both sides. We suggest that the asymmetry was caused by a larger spindle afferent activity on the ipsilateral as compared to the contralateral side, and that the all-over decrease of muscle activity was due to gradual reduction of activity from periodontal pressoreceptors.

The present study deals with the influence of a unilateral premature contact on muscle activity during maximal bite in the intercuspal position. It was the aim to explore the immediate response of the temporal and masseter muscles to such contacts located on first molars.

SUBJECTS

The experiments included one female and three males, 20-35 years of age, with complete support in the lateral sections of the dentition, and without neuromuscular disorders or functional disorders of the temporomandibular joint.

RESULTS

Unilateral premature contact caused a marked asymmetry between the action of ipsilateral and contralateral muscles during maximal bite. Compared to control values (undisturbed occlusion) the general tendency of elevator activity with strips inserted was an increase on the side of the premature contact and decrease on the opposite side. However, with increasing thickness of the overlay the ipsilateral activity returned to the level of control, while the mean voltage in the contralateral muscle continued to decline.

Anterior temporal muscles - In terms both of the average level and of the peak of the mean voltage, differences between the activity in the ipsilateral and the contralateral muscles were highly significant ($P < 0.01$), irrespective of the thickness of the overlays. The increment of muscle action on the side of the premature contact was marked in terms of peak values with one layer ($P < 0.001$), two layers ($P < 0.01$), and three layers ($P < 0.05$), but not with four layers while the average level did not change significantly. Contralateral, reduction during the experimental conditions was more pronounced in terms of the average level ($P < 0.01$ and $P < 0.001$) than of the peak.

Masseter muscles - In spite of larger numerical differences, premature contact was reflected less in the activity in the masseter muscles as compared to the other muscles under study. Premature contact caused a marked difference between the overlay-side and contralateral muscles ($P < 0.01$ to $P < 0.05$), but the average level of ipsilateral activity did not differ significantly from the control level at any number of layers, and peak values were only enhanced with 0.05 and 0.10 mm ($P < 0.05$). Contralaterally, the average level of the mean voltage decreased with one, three and four strips ($P < 0.05$), while peak values did not differ significantly from control, irrespective of the number of strips inserted.

DISCUSSION

From electromyographic studies of patients with functional disorders of the chewing apparatus (7, 9, 11, 12, 20, 21) and subjects in whom function was impaired by artificial premature contact (22), it has been inferred that occlusal interferences disturb muscle function. However, the initial influence of such interferences on muscle coordination has not been specified. The present study has demonstrated that biting in the intercuspal position with unilateral premature tooth contact causes asymmetric action of the elevators, with strongest activity on the side of the interference.

The significant findings of the present study were 1) asymmetry of muscle activity on the side of premature contact and, with this asymmetry maintained, 2) a reduction of mean voltage on both sides with increasing height of the overlay. A comparison with data obtained during unilateral contact at larger jaw separation emphasizes these two features.

In a controlled longitudinal study at the Department of Stomatognathic Physiology at Karolinska Institute in Stockholm, Riise and Sheikholeslam analyzed the influence of an intercuspal occlusal interference that was experimentally introduced in 11 normal subjects. All subjects had complete natural dentition without any symptoms of functional disorders.

Riise and Sheikholeslam's thorough study of quantitative EMG on the temporalis and masseter muscles of the subjects resulted in three important papers that were published in the *Journal of Oral Rehabilitation* in 1982, 1983 and 1984. Using extensive statistical tests, these studies concluded that:

- 1] "Experimental occlusal interferences similar to those often produced in the daily dental practice of occlusal rehabilitation, such as fillings, crowns, and bridges affect the neuromuscular pattern of postural activity in the mandibular elevators at rest. The pattern of postural activity is influenced sometimes as early as one hour after the insertion (of interference). After 48 hours, there was a significant increase of the activity in the anterior temporal muscles. This increased activity persisted (up to one week) after the interference was removed."
- 2] "A single, small occlusal interference is able to disturb the almost symmetrical pattern of muscular activity. This was especially evident during submaximal bite. After the application of the interference, the maximal (bite) muscular activity was reduced significantly in all muscles under study."
- 3] "Disturbance of the occlusion by a small, experimental interference in the intercuspal position significantly changes the timing and the level of muscular activity during mastication, at least over the experimental period (one week). Furthermore, there was also a change towards a unilateral chewing pattern, which, if persisting over the years, has been shown to evoke sequelae in the masticatory system. The importance of occlusal stability is further emphasized by the fact that four (of eleven) subjects broke off participation in the investigation because of pain in jaw muscles and/or temporomandibular joints caused by the interference."

Riise, C., and Sheikholeslam, A. The influence of experimental interfering occlusal contacts on the postural activity of the anterior temporal and masseter muscles in young adults. *J. Oral Rehabilitation*, 9: 419-425, 1982.

SUMMARY

The effects of an intercuspal occlusal interference on the pattern of postural activity of the anterior temporal and masseter muscles were studied in eleven volunteers with complete, natural dentitions. The results indicate that, in man, there is postural activity in the anterior temporal and sometimes the masseter muscles. The pattern of postural activity is influenced by the occurrence of an experimental occlusal interference, sometimes as early as 1 hour after the insertion. After 48 hours there was a significant increase of the activity in the anterior temporal muscles. This increased activity persisted until the interference was removed 1 week later and had almost disappeared 1 week after the removal.

INTRODUCTION

In subjects with unilateral cross-bite, Troelstrup & Moller (1970) and Moller & Troelstrup (1975) demonstrated that the postural activity in the posterior temporal muscle tended to predominate on the side of the cross-bite, and this tendency was interpreted as an adaptation to the cross-bite. Ingervall & Thilander (1975) have confirmed these observations. In patients with functional disorders in the chewing muscles, the level of the postural activity was found to be increased especially in the anterior temporal muscle (Lous, Sheikholeslam & Moller, 1970). Deliberate relaxation in the sitting position with a headrest had little effect in such patients (Moller, Sheikholeslam & Lous, 1971) though in the supine position, the activity in the anterior temporal muscle was reduced virtually to the same level as that in relaxed normal subjects.

The purpose of the present study was to investigate whether there is any postural activity in the mandibular elevators at rest and, if there is such an activity, what effect an occlusal interference can have on the neuromuscular pattern.

MATERIALS AND METHODS

Eleven male dental students, aged 24-32 years, volunteered for this study. They were selected according to the following criteria: (1) with complete natural dentitions, (2) without any symptoms of functional disorders in the stomatognathic system. The surface electrode was chosen in preference to the needle electrode to avoid pain and anxiety effects on muscular tension. Furthermore, the surface electrode is able to sample the activity from a greater number of units (Yemm, 1977). The postural activity was recorded in the anterior temporal and masseter muscles in alert subjects, sitting upright, with heads unsupported and with eyes open.

The artificial occlusal interference was inserted each time by the same operator. The interference was a small, rounded, and 0.5 mm high amalgam filling on the maxillary right first molar (the mesial facet of the disto-buccal cusp).

CLINICAL COMMENTS

Three hours after insertion of an occlusal interference, seven subjects complained of pain, tenderness and fatigue mostly in the elevator muscles. Psychologically, most of the subjects felt that the filling caused them to be under constant nervous tension and reported awareness of bruxism. Two knew that they tried to avoid the occlusal interference. In eight subjects, symptoms of functional disorders developed within less than 12 hours, and shiny facets appeared on the surface of the amalgam interference.

RESULTS

The alert pattern of postural activity before the insertion of an occlusal interference showed that there were some active tonic units in the anterior temporal muscle (Fig. 1). Some of these units were able to continue firing for more than 15 mm without any sign of fatigue. In the masseter muscle, postural activity was usually absent, but occasionally there was slight tonic activity (four subjects).

One hour after the insertion of an occlusal interference, there were no significant changes in the pattern of the postural activity except in two subjects, who showed increased activity in the anterior temporal muscle of one side. After 48 hours, the increase of the postural activity was significant ($t:P \leq 0.01$) in the right and left anterior temporal muscles (Fig. 2, Table 1). In the masseter muscles there was no significant change except in four subjects with an increased postural activity.

One week after the insertion of the interference there was still a significant (Table 2) increase of postural activity in either the right or the left anterior temporal muscle while there was no significant change in the masseter muscles. Immediately after the removal of the remaining interference there was no significant response in the pattern of postural activity. One week later the postural activity had returned almost to its original pattern in all subjects.

DISCUSSION

After removal of the remaining occlusal interference, there was no immediate response in the pattern of the postural activity and it took about a week for adaptation to a new posture, thus, the fusimotor drive can be a possible cofactor for postural hyperactivity.

After about an hour, in two subjects the early response to occlusal interference appeared as asymmetrical hyperactivity in either the right or the left temporal muscle. This early, asymmetrical spontaneous postural hyperactivity probably depended on an attempt to shift the position of the mandible to avoid the interference. Within 48 hours, the postural hyperactivity increased in the anterior temporal muscles of eight subjects, and in four of these even in the masseter muscles. As the subjects were instructed not to keep their teeth in contact during the recordings, such contact could not initiate the hyperactivity. Moreover there was no significant change in the pattern of postural activity immediately after removal of the occlusal interference. It seems that the hyperactivity shown in the present investigation may have been the result of increased fusimotor drive caused by stimuli from the occlusal interferences. In the long run, the hyperactivity may be followed by structural adaptation such as teeth movements, muscular reactions and remodelling of the temporomandibular joints or may lead to pathological changes in the masticatory system.

CONCLUSION

The present results indicate that there is postural activity in the anterior temporal and sometimes in the masseter muscles, and that experimental occlusal interferences similar to those often produced in the daily dental practice of occlusal rehabilitation, such as fillings, crowns, and bridges effect the neuromuscular pattern of postural activity in the mandibular elevators at rest.

Sheikholeslam, A., and Riise, C. Influence of experimental interfering occlusal contacts on the activity of the anterior temporal and masseter muscles during submaximal and maximal bite in the intercuspal position. J. Oral Rehabilitation, 10: 207-214, 1983.

SUMMARY

The effects of an intercuspal occlusal interference on the pattern of activity of the anterior temporal and masseter muscles during submaximal and maximal bite, were studied in eleven volunteers with complete, natural dentitions.

The results show that, during maximal and submaximal bite the occlusal interference (about 0.5 mm) in the intercuspal position is able to disturb the almost symmetric pattern of muscular activity in the anterior temporal and masseter muscles. Further, the level of muscular activity during maximal bite decreased significantly in all muscles studied. In some subjects, the decrease of muscular activity could still be observed one week after insertion of the interfering contact. After eliminating the interference, the muscular coordination pattern improved and the level of muscular activity increased significantly.

INTRODUCTION

The static bite force of the masticatory muscles was investigated as early as the 17th century.

Mechanical pressure applied to the teeth is known to stimulate periodontal receptors (Pffaffman, 1939; Ness, 1954). These receptors have been considered by some authors to play a limiting role in maximal bite force (Black, 1895; Schroeder, 1927; Worner & Anderson, 1944; Steenberghe & De Vries, 1978), while others have reported a positive feedback on the degree of elevator muscle contraction (Czeche, 1968; Arnold, 1972; Lund & Lamarre, 1973)

There is evidence that the maximal bite force (Molin, 1972; Helkimo, Carlsson and Carmeli, 1975) and the electrical muscle activity during maximal bite in the intercuspal position (Sheikholeslam, Moller and Lous, 1980) are significantly weaker in patients with functional disorders of the masticatory system than in controls without such disorders. In a short-term clinical and electromyographic study of the effects of an intercuspal interference (gold-inlay) in one of the mandibular first molars, Randow et al. (1976) reported that the interfering contact immediately disturbed the coordinated pattern of muscular activity in the elevators during biting with maximal effort in the new intercuspal position. Furthermore, all subjects but one showed signs and symptoms of functional disorders of the masticatory muscles during the 2-week experimental period.

The purpose of the present study was to investigate quantitatively the short-term effects on the pattern of muscular activity of an experimental occlusal contact interfering in the intercuspal position during submaximal and maximal bite.

MATERIALS AND METHODS

Eleven males, aged 24-32 years, with complete natural dentitions, excellent periodontal status and without signs and symptoms of functional disorders, volunteered for the present investigation. The electromyographic methods have been described previously (Riise & Sheikholeslam, 1982). The electrical activity in the anterior temporal and masseter muscles was recorded bilaterally, using surface electrodes, during: (1) submaximal bite in the intercuspal position (i.e. a continuous EMG recording of the gradually increasing muscular activity from the mandibular rest activity to almost 20% of the full effort of the right anterior temporal muscle - 'reference muscle'); (2) maximal bite in the intercuspal position (i.e. hardest possible clenching for 1 second and relaxation for 3 mm between each clenching to avoid muscular fatigue).

The muscular coordination and correlation pattern during submaximal bite was evaluated semiquantitatively, while the full effort activity was calculated as the average of the electromyographic mean voltage of four recordings. EMG recordings were performed before, 1 hour, 48 hours, and 1 week after the insertion of the interfering filling, as well as before and immediately after elimination of the interference. After 1 week or more, final control recordings were made. In the statistical evaluation the difference between means of distributions were matched using the Student's t-test for paired comparisons.

CLINICAL FINDINGS

In less than 12 hours following the insertion of the interfering amalgam filling, signs and symptoms of functional disorders had developed in eight subjects. Within a week the occlusal interference was reduced in height and the symptoms gradually subsided. However, in four subjects, clinical examination revealed that moderate signs of functional disorders persisted which disappeared within a week after eliminating the interfering filling.

RESULTS

The immediate EMG recordings after the insertion of the interfering filling showed that in eight subjects, there were two or more different patterns of muscular activity during submaximal and maximal bite in the altered intercuspal position. During submaximal bite the occlusal interference disturbed the almost symmetrical and coordinated pattern of muscular activity in the anterior temporal and masseter muscles in nine subjects. The electrical activity during the maximal bite in the altered intercuspal position was significantly reduced ($P < 0.001$) in all muscles studied.

Forty-eight hours after inserting the occlusal interference, in seven subjects, the EMG recording during submaximal bite still showed lack of coordination and symmetry in the activity pattern of the anterior temporal muscles and in three subjects also of the masseters. The electrical activity during maximal bite showed a significant decrease ($P < 0.01$) in all the muscles studied when compared to the activity before the insertion of an occlusal interference.

After one week, in four subjects, the pattern of EMG during the submaximal bite showed that, still, there was some asymmetry and lack of coordination in the activity of the temporal muscles. The electrical activity during the maximal bite was significantly decreased in the right anterior temporal ($P < 0.001$) and the right masseter muscles, ($P < 0.05$).

Immediately after removal of the remaining occlusal interference the earlier asymmetric submaximal EMG pattern became more symmetric, and furthermore, the electrical activity of the maximal bite in the intercuspal position increased significantly. However, when the EMG at maximal bite was compared, directly after the removal, to that before insertion of the occlusal interference, the results still showed a significantly reduced electrical activity in the right anterior temporal and masseter muscles (size of occlusal interference). One to four weeks after the elimination of the interfering occlusal contact, in all but one subject, the EMG of maximal bite in the intercuspal position showed no statistical difference when compared to that before insertion of the experimental interference.

DISCUSSION

In the present investigation, the disturbance in coordination and correlation of elevator muscle activity during the maximal bite after insertion of an interfering amalgam filling almost disappeared after the elimination of the interference.

The most striking result of the present study was finding that a single, small occlusal interference is able to disturb the almost symmetrical pattern of muscular activity. This was especially evident in the anterior temporal muscles during submaximal bite.

After application of the interference, the maximal muscular activity was reduced significantly in all muscles under study.

There are several assumptions which could be advanced partly to explain the incoordinating effects of an occlusal interference on the muscular contraction pattern of maximal bite and the reduction of the level of activity:

- (1) It may be the effect of an increased negative feedback from high threshold mechanoreceptors and nociceptors in or around the teeth (Anderson & Picton, 1958) with the occlusal interference.
- (2) It may be due to a reduction of the number of teeth in contact in the altered intercuspal position, as Steenberghe & De Vries (1978) reported that there was a positive correlation between the maximal bite force which can be reached and the number of teeth in contact. Since the maximal bite force has to be distributed over a smaller number of teeth in contact, the high threshold mechanoreceptors and nociceptors in and around these teeth will be stimulated more easily, thus giving a negative feedback to the mandibular elevator motoneurons. On the other hand, assuming that the periodontal receptors have a facilitating effect on the motoneurons of the jaw closing muscles via cortical level (Lund & Lamarre, 1973), the degree of positive feedback would be reduced with a less number of teeth in contact.
- (3) It may be due to the discrepancy between the direction of the resultant of the bite in the altered intercuspal position and the former forces acting on the teeth. As a result of altered contact positions, the teeth may be pushed in a different direction by forces different to those for which the actual periodontal receptors have been programmed and, consequently, their feedback may be changed. By recording the activity from the inferior alveolar nerve in man, Johansson & Olsson (1976) reported that a mechanical stimulus directed distally or lingually on a lower premolar evoked a vigorous response whereas forces applied in the mesial and buccal direction did not. Further, they found that lingually and axially directed stimuli were the most efficient to excite this tooth.

- (4) Displacement of the condylar position may also have changed the feedback to the elevator muscles, as it was reported by Abe, Takata & Kawamura (1973) that the receptors in the TMJ are able to modify the stimulation threshold of the motoneurons of the masticatory muscles.
- (5) Psychological factors, such as fear of pain and fracture of teeth may have played some minor role in the reduction of muscular activity. However, the subjects were instructed and encouraged to clench as hard they ever could.

The increase of muscular activity after removal of the experimental occlusal interference was significant. The explanation may be that the factors which had increased the inhibitory feedback during maximal bite, had been reduced. However, the level of muscular activity on the right side (interference side) did not return to the pre-experimental level immediately after removal of the interference. This reduction of muscular activity may be due to inhibition arising from pain in or around the teeth which interfered, and/or muscular fatigue, spasm caused by development of functional disorders and postural hyperactivity (Riise & Sheikholeslam, 1982).

The results of this study are in line with Bakke & Moller (1980), who demonstrated that unilateral premature occlusal contacts (by using layers of celluloid strips), as small as 0.05 mm, caused a significant asymmetry of action in the temporal and masseter muscles during the maximal bite. Furthermore, by increasing the thickness of the premature contact the muscular activity decreased in parallel on the ipsi- and contralateral sides.

CONCLUSION

The results of the present study suggest that, most probably, the periodontal receptors in the man are able to modify the pattern of muscular activity of the anterior temporal and masseter muscles during submaximal and maximal bite. Furthermore, disturbances of the input of the periodontal receptors caused by an occlusal interference in the intercuspal position may lead to functional disorders in the stomatognathic system.

Riise, C. and Sheikholeslam, A. The influence of experimental interfering occlusal contacts on the activity of the anterior temporal and masseter muscles during mastication. *J. Oral Rehabilitation*, 11: 325-333, 1984.

SUMMARY

Quantitative electromyography (EMG) was used to study, in eleven volunteers with complete, natural dentitions, the effects of an experimental intercuspal occlusal interference on the pattern of activity of the anterior temporal and masseter muscles during mastication.

The results show that a small occlusal interference (about 0.05) in the intercuspal position can change the coordination of muscular activity during mastication. In general, there was a prolonged contraction time as well as a reduction of the activity in all the investigated elevators, especially on the side of the interference. Furthermore, after 48 h several subjects preferred to chew unilaterally. After removal of the interference, the pattern of coordination of muscular activity returned almost to the pre-experimental pattern within 2 weeks.

INTRODUCTION

Human mastication is considered to be an event where the rhythm is generated by a brainstem 'pattern generator' as described by Dellow & Lund (1971), Lund (1976), Nakamura et al. (1976) and Dubner, Sessle & Storey (1978). The generator can be modified by inputs from a variety of central as well as peripheral sites. This partly explains the difficulties in interpreting the results obtained by different observers using different methods concerning the effects of occlusal interferences on the mastication. Such effects on human mastication have been studied by observing changes in the masticatory system after either experimentally inducing occlusal interferences (Anderson & Picton, 1958; Schaerer, Stallard & Zander, 1967); De Boever, 1969; Hannam et al., 1977; Hannam & Lund, 1981), or removing natural interferences, in the latter case in healthy individuals as well as in patients (Ramfjord, 1961; Hannam et al., 1977; Ingervall & Carlsson, 1982 and Moller, Sheikholeslam & Lous, 1984).

One of the main goals in the field of stomatognathic physiology has been to understand the interaction between muscular activity and the interocclusal relationship during mastication. The muscular activity during natural chewing has been studied quantitatively in detail by Moller (1966) who found the principal feature of the chewing pattern to be: lead in time of the temporal muscle and predominance in strength of the masseter muscle on the side of the chewing.

The purpose of the present study was to investigate quantitatively the short-term effects of an experimental occlusal interference in the intercuspal position on the pattern of muscular activity during mastication.

MATERIALS AND METHODS

Eleven males, aged 24-32 years, with complete natural dentitions, excellent periodontal status and without signs and symptoms of functional disorders, *volunteered for the present investigation. The electrical activity in the anterior temporal and masseter muscles was recorded bilaterally, using surface electrodes. The electromyographic methods have been described in detail previously (Moller, 1966, 1974; Riise & Sheikholeslam, 1982).

The patterns of elevator activity during natural chewing (apple) were measured quantitatively, with onset of the activity in the right anterior temporal muscle as reference. Onset and cessation of activity were measured directly on the electromyograms, while the tracing of the mean voltage was used to measure the time course to 50% maximal mean voltage ascending (MV1), to maximal mean voltage (MV2), and to 50% maximal mean voltage descending (MV3).

The experimental intercuspal interference was a rounded amalgam filling, 2 mm in diameter and about 0.05 mm in height, inserted on the maxillary right, first molar on a pre-existing amalgam filling.

CLINICAL COMMENTS

Within less than 12 hours following the insertion of the interfering amalgam filling, signs and symptoms of functional disorders had developed in eight subjects, and after 48 hours in nine subjects. Four of these withdrew from the investigation after 48 hours because of their symptoms, and the interferences were removed. In the remaining five subjects with signs and symptoms the amalgam interference was somewhat reduced in height and the symptoms gradually subsided. Clinical examination, however, revealed that moderate sign of functional disorders still persisted in four subjects at the end of the experimental period, but disappeared within a week of eliminating the interfering filling.

RESULTS

Before insertion of the occlusal interference the EMG-pattern of muscular activity showed that all individuals but one chewed on the right and left side as well as bilaterally.

DISCUSSION

The results of the present study demonstrated, in general, that an occlusal interference as small as about 0.05 mm (inserted in the intercuspal position in a pre-existing amalgam filling) can influence the pattern of muscular coordination during natural mastication, and can reduce the intensity and prolong the duration of muscular activity.

CONCLUSION

Disturbance of the occlusion by a small, experimental interference in the intercuspal position significantly changed the timing and the level of muscular activity during mastication, at least over the experimental period (1 week). Furthermore, there was also a change towards a unilateral chewing pattern, which, if, persisting over the years, has been shown to evoke sequelae in the masticatory system. The importance of occlusion in the investigation of pain in jaw muscles and/or temporomandibular joints caused by the interference is apparent.

Kydd et al., in a controlled 1986 study induced subjective pain and fatigue in 30 healthy patients as a result of unilateral isometric biting with a uniform force of 55 N, a level of force that caused discomfort and pain. The authors concluded that "In the subjects with contralateral pain discomfort, EMG evaluation demonstrated that integrated EMG activity on the non-stressed contralateral side was twice that of the ipsilateral side where the force was applied".

Kydd, W.L., Choy, E., & Daly, C. Progressive jaw muscle fatigue and electromyogram activity produced by isometric unilateral biting. *The Journal of Craniomandibular Practice*, (4)1: 18-21, 1986.

The purpose of our study was to quantify the duration of force required during unilateral biting to produce the onset of subjective fatigue and pain in the masseter and anterior temporalis muscles of healthy adult female subjects. We defined pain-fatigue as the appearance of an initial, intense discomfort in one or more jaw muscles after the onset of unilateral biting or clenching.

MATERIALS AND METHODS

The 30 human subjects were healthy female volunteers. The mean age of the subjects was 28 years, with a range from 19 to 43 years. All the subjects were clinically examined by careful palpation of the jaw muscles and the TMJs and all were symptomatic.

RESULTS

In 10 of the test subjects who had complained of pain on the contralateral side and on whom EMG recordings were made, we found the mean integrated EMG in the masseter to be 90% greater on the contralateral side than on the ipsilateral side in all 10 subjects. This increase occurred on the contralateral side whether biting first took place on the right or left side.

SUMMARY

As a result of unilateral isometric biting with a uniform force of 55 N, discomfort and pain occurred. The localization of discomfort and pain occurred primarily on the side contralateral to the force application and near the origin of the masseter, slightly inferior in the zygomatic arch. In the subjects with contralateral pain discomfort, EMG evaluation demonstrated that integrated EMG activity on the nonstressed contralateral side was twice that of the ipsilateral side where the force was applied.

STUDIES THAT DOCUMENT THE RELATIONSHIP BETWEEN
ELECTROMYOGRAPHY AND MUSCULAR FORCE

This early classic work of Lippold, at the Department of Physiology of University College in London, established the linear relation between integrated electromyograms and the tension produced by a voluntary isometric contraction in a human muscle. The author always found a direct linear relationship between integrated EMG output and muscle activity using thirty experiments on different subjects.

Lippold, O.C.J. The relation between integrated action potentials in a human muscle and its isometric tension. J. Physiol., 117: 492-499, 1952.

The results show that under the limited conditions of the experiment there is a linear relation between the integrated electromyogram and the tension produced by a voluntary isometric contraction in a human muscle.

Although there is no proportionality between the mechanical and the electrical responses of a single motor unit, when the summated effect of a large number of units is recorded by surface electrodes from the whole muscle, the variation is statistically cancelled out. It has been shown (Adrian & Broak, 1929; Eccles & Sherrington, 1930; Gilson & Mills, 1941) that changes in the strength of contraction of a muscle are brought about in two ways: as the strength of contraction increases the number of motor units active becomes greater and there is a rise in the frequency at which these units repetitively contract.

Both these factors must increase the integrated electrical output of the muscle, so that the existence of this linear relationship indicates that the recruitment of motor units, bringing about increased strength of contraction, is spatially random. Similarly, there are either random increments of discharge frequencies of the active units, or once a particular unit has become active its rate of contraction smoothly increases.

SUMMARY

- [1] The relation between the isometric tension of a voluntarily-contracting human muscle and its integrated electromyogram has been investigated.
- [2] In thirty experiments on different subjects the relationship is always directly linear.
- [3] The coefficient of correlation in these experiments varies between +0.93 and -0.99

Bigland and Lippold, in a controlled study at the Department of Physiology of University College in London, showed a linear relation between electrical activity and tension during constant or zero velocity of shortening. This classic study confirms the rationale for the clinical EMG protocol using maximal bite or clench. The function EMG test is designed to quantify the efficacy of muscle motor unit recruitment at a given mandibular position. This test shows that as the electrical activity increases, the proportion of overlap between potentials arising in different parts of the muscle remains constant. The excitation is related to the number and discharge frequency of active units.

Bigland, B. and Lippold, O.C.J. The relation between force, velocity and integrated electrical activity in human muscles. *J. Physiol*, 123: 214-224, 1954.

DISCUSSION

These results show a direct proportion between the integrated electrical activity in a muscle and the tension it is exerting, during constant (or zero) velocity of shortening (or lengthening). This indicates that, as the electrical activity increases, the proportion of overlap between potentials arising in different parts of the muscle, causing addition and subtraction in the final output, remains constant. Thus at any given velocity the area under the action potential curve is a measure of the 'excitation' in the muscle.

The excitation is related to the number and discharge frequency of active units. Assuming that the fibres are randomly distributed within the muscle in terms of the size and hence of the force of contraction of each fibre, the tension developed in the muscle must be related directly to the number of Units which are active. It has been shown in nerve muscle preparations that the tension developed in response to maximal shocks is directly proportional to the frequency of stimulation, until a maximum tension is reached (Adrian & Bronk, 1929; Brown & Burns, 1949). This is also true in intact human muscles (Bigland & Lippold, unpublished). Thus, within certain limits on these grounds, any changes in either the number or frequency of active units would be expected to result in a linear relation between electrical activity and tension.

SUMMARY

Tension, velocity and electrical activity are thus interdependent, and integration of the electrical record provides a composite measure of the number of active fibres and their frequency of excitation.

In a carefully controlled study of voluntary isometric biting forces at maximal and submaximal levels, Molin (1972) demonstrated that there were progressively increasing force differences between the (control and patient) groups". The joint study conducted at University of Karolinska and University of Gothenberg in Sweden concluded that "the patients generally produced only one half to two thirds of forces produced by the control subjects".

Molin, C. Vertical isometric muscle forces of the mandible: A comparative study of subjects with and without manifest mandibular pain dysfunction syndrome. Acta Odont. Scand., 30: 485-499, 1972.

ABSTRACT

The aim of the investigation was to study isometric biting forces at 'maximal' as well as at submaximal levels as defined in subjective terms. Special attention was paid to differences between subjects with and without manifest mandibular pain dysfunction syndrome (MPD). Thirty-one female subjects with manifest MPD constituted the patient group and 30 healthy females the control group. The reliability of the measurements was tested and the results obtained in both groups indicated that the discriminating capacity was not affected by the disorder. Except for the lowest force level (approximating the absolute threshold), substantial force differences between the groups were obtained. These differences increased with the force levels, and the patients generally produced only one-half to two-thirds of the forces produced by the control subjects.

MATERIAL AND METHOD

SUBJECTS

The experimental group consisted of the same 31 female patients from the Department of Oral and Jaw Diseases, Karolinska Sjukhuset, Stockholm, who had taken part in the study of the horizontal mandibular forces (Marklund & Molin, 1972). Their age range was 16-45 with a mean of 18.3 years. All of them had manifest mandibular pain dysfunction syndrome (MPD), (Molin, 1973a).

The control group consisted of the same 30 healthy females (dental nurses, student dental nurses and student physiotherapists) who also participated in the previous investigation. They were aged 18-28 with a mean age of 22.1 years. The control subjects were paid. None of the subjects had appreciable bite defects or periodontal disease.

APPARATUS

The biting force transducer was designed according to principles outlined by Linderholm and Wennstrom (1970). In principle the transducer consisted of two cantilever beams with electrical strain-gauges cemented close to the fixed ends.

PROCEDURE

The subject was instructed to perform close bites in accordance with the rating scale. The scale was placed in front of the subject, and the test leader pointed out the requested biting force category. The subject was asked to bite intermittently for periods of about 3 seconds with 10 seconds rest intervals. To keep the effects of experimental praxis, fatigue and memory errors under control, the order of the biting force levels was rotated at random.

RESULTS

When the patients were compared with the control subjects (Table IV), it can be seen that there were progressively increasing force differences between the groups with rising values on the rating scale. The degree of significance also increased with rising force levels. The 'maximum forces' (initial 'maximum' measurements and recordings at scale level 5) produced by the patients were all between two-thirds and half of those produced by the control subjects.

In a detailed study of surface electromyography versus muscular force conducted at the University of Alberta's Department of Physiology, Milner-Brown (1975) demonstrated that integrated "EMG is linearly related to the force produced by the muscle.

Milner-Brown, H. S. The relation between the surface electromyogram and muscular force. J. Physiol. 246: 549-569, 1975.

SUMMARY

1. Motor units in the first dorsal interosseus muscle of normal human subjects were recorded by needle electrodes, together with the surface electromyogram (e.m.g.). the wave form contributed by each motor unit to the surface e.m.g. was determined by signal averaging.
2. The peak-to-peak amplitude of the wave form contributed to the surface e.m.g. by a motor unit increased approximately as the square root of the threshold force at which the unit was recruited. The peak-to-peak duration of the wave form was independent of the threshold force.
3. Large and small motor units are uniformly distributed throughout this muscle, and the muscle fibres making up a motor unit may be widely dispersed.
4. The rectified surface e.m.g. was computed as a function of force, based on the sample of motor units recorded. The largest contribution of motor unit recruitment occurs at low force levels, while the contribution of increased firing rate becomes more important at higher force levels.
5. Possible bases for the common experimental observation that the mean rectified surface e.m.g. varies linearly with the force generated by a muscle are discussed. E.m.g. potentials and contractile responses may both sum nonlinearly at moderate to high force levels, but in such a way that the rectified surface e.m.g. is still approximately linearly related to the force produced by the muscle.

In a 1978 study of EMG versus static loading of the mandible, Pruim (et al, at the Department of Orthodontics, University of Groningen, The Netherlands) further confirmed "the linear relationship between integrated EMG and the (mandibular) force exerted by individual muscles in isometric conditions." The authors demonstrated that "at high bite force levels the activities in all muscle pairs are considerably increased."

Pruim, G.J., Ten Bosch, J.J., and De Jongh, H.J. (1978) Jaw muscle EMG activity and static loading of the mandible. *J. Biomechanics*. 11, 389-395.

ABSTRACT

A method is described to relate jaw muscle EMG-activity to static bite forces. Bite forces are measured bilaterally in several reproducible positions on the human dentition by means of small wedge shaped transducers. Electromyographic methods are used to derive a relative measure of the activity in the opener and closer muscles. Visual feedback methods are used to obtain bite recordings at various levels of bite force and muscle activity.

There is no reason to doubt the linear relationship between integrated EMG activity and the force exerted by individual muscles in isometric conditions. The anterior and posterior parts of the temporal muscle show a different functional behavior. The role of the opener muscles as antagonists is of such importance, that it should not be neglected in muscle force analysis.

MATERIALS

Seven adult male students served as experimental subjects, some of them several times. The subjects had no temporomandibular joint dysfunctions, as judged by subjective symptoms and by objective symptoms such as manual palpation during mandibular movements.

METHODS

ELECTROMYOGRAPHY

To record muscle action potentials bipolar surface electrodes were applied.

RESULTS

It can be demonstrated that at high bite force levels the activities in all muscle pairs are considerably increased. To which extent the increase occurs depends on the muscle.

DISCUSSION

The question of linear or ailinear relationships between the integrated EMG (EMGI) and isometric muscle force has been discussed by many authors (Lippold, 1952; Bigland and Lippold, 1954a,b; Ralston, 1961; Ahlgren, 1967; Ahlgren and Owall, 1970; Goubel, 1971; DeLuca and Forrest, 1973; Cnockaert et al., 1975; Yemm, 1977; Hof and Van den Berg, 1977; Maton and Bouisset, 1977). Common postulate was the existence of a linear relationship between integrated EMG and isometric muscle force, as far as contractions at submaximum level are concerned. As can be shown in Fig. 4, our experimental results parallel previous findings. However, it can also be noticed that antagonistic activity occurs as soon as agonistic muscle activity deviates from linear behavior.

In most investigations bearing on jaw mechanics, bite forces were measured during unilateral biting (e.g. Ahlgren and Owall, 1970; Carlsson, 1974; de Boever, 1975; Mansour and Reynik, 1975). In our opinion in this situation a pattern of forces could arise at the contralateral (balancing) side, which may result in a departure from static and isometric conditions. Therefore bilateral biting was assumed to be a better method for loading the mandible.

In those papers where other joints were investigated (e.g. Lippold, 1952; Bigland and Lippold, 1954; Goubel, 1971; De Luca and Forrest, 1973; Cnockaert et al., 1975; Hof and Van den Berg, 1977), forces were transferred to the force transducers through intervening soft tissues. In such cases at high force levels an inhibition initiated in the soft tissues can never be excluded. In this investigation the bite forces were transferred to the skull, with only the periodontium as underlying tissue. By means of the splint construction the bite forces were evenly distributed over the dentition. Thus an inhibition initiated by the pressoreceptors in the periodontium was prevented as far as possible and high bite forces could be expected. Moreover, the feedback methods stimulated the subjects to exert full effort.

Since the shape of the articular surfaces in the temporomandibular joints does not mechanically prevent displacement of the condyles, maintenance of the mandibular position must be provided by muscle action. In our experiments the acrylic splints and the flexible telescope construction served as an aid to coordinate this muscle action.

STUDIES THAT DOCUMENT THE REPRODUCIBILITY AND RELIABILITY OF SURFACE ELECTROMYOGRAPHY

At the University of Technology (The Netherlands) in 1986, Hermens et al. conducted a thorough study and literature review on the clinical applications and reproducibility of surface electromyography. Advantages of surface over needle electrodes in electromyography were cited.

Hermens, H. J., Boon, K. L., and Zilvold, G. The clinical use of surface EMG. *Medica Physica*, 9: 119-130, 1986.

ABSTRACT

The use of surface EMG as a tool for quantification is described. First the specific advantages of surface EMG are discussed. Time registrations are processed by means of a computer, From each registration an amplitude histogram and a power density spectrum is calculated. The parameters standard deviation, kurtosis and skewness are used in order to describe the histogram. The power density spectrum is characterized by a number of frequency parameters (first peak, maximum, median, - 6dB and - 10dB) and relative power parameters (relative power in % above - 6dB, - 10dB and 100 Hz). Furthermore the gradient EMG - activity (expressed in standard deviation) and force and the quotient between antagonist and agonist EMG activity are studied. By means of a pilot investigation a standard procedure is evaluated and "normal values" are found.

INTRODUCTION

It can be observed that with needle EMG the properties of the motor unit action potentials are primarily registered (firing frequency and shape of the potential), whereas with surface EMG more or less the activity of a large part of a muscle is registered. In this way a better idea of the functioning of a muscle is obtained.

This is one of the main reasons why surface EMG is often applied in kinesiological studies.

Another important advantage of the use of surface electrodes is its noninvasive character. In the clinical situation this point proves to be very important especially with follow- up investigations and with investigations with children.

In the literature many models can be found that relate physiological processes to characteristics of the surface EMG signal (Lindstrom, 1974; Guha and Anand, 1978)

THE PARAMETERS TO DESCRIBE SURFACE EMG

In most investigations the IEMG appears to increase linearly with the exerted isometric force in a rather large region (Rau, 1973; Hof van v. d. Berg, 1981). An additional increase is caused by fatigue (Petrofsky, 1979; Kramer, 1979)

DISCUSSION

In this study we tried to answer the question: can surface EMG be applied in a clinical situation, especially as a tool for quantification? In our opinion it is obvious that needle EMG is hardly applicable for quantification. Patterns obtained by means of needles are almost always only related to single motor units and the relative position of the leadoff area causes a large variability with respect to the registered potentials. With surface EMG, leadoff electrodes are always situated outside the motor unit area. The signal is dominated by an interference pattern caused by the summation of many motor unit action potentials. If disorders occur, changes can be detected in this signal in a more reliable way, at least from a statistical point of view. Our results show that surface EMG can certainly lead to a reproducible method of quantification.

It is possible to indicate a range of "normal" values to discern pathology. It is also possible to measure changes in parameters during a follow-up investigation.

The reproducibility of the parameters derived from the spectrum is somewhat better compared with the results described by Viitasalo and Komi (1975) although comparison is somewhat difficult due to the different presentation of the spectrum. The improved reproducibility will be obtained by the longer time registration (2 seconds) that is used to calculate the spectrum.

Riise (in the Department of Stomatognathic Physiology, Karolinska Institutet, Stockholm, Sweden) strongly prefers the use of bipolar surface electrodes to evaluate the general activity of the anterior temporal and masseter muscles.

Erickson (1982) also advocates the preferred use of surface electrodes due to the mixed, heterogeneous fibers of the mandibular elevator muscles.

Riise, C. Clinical and electromyographic studies on occlusion. From the Department of Stomatognathic Physiology, Karolinska Institutet, Stockholm, Sweden, pp. 20-21, 1983.

The preference of bipolar surface electrodes (Riise & Sheikholeslam - 1982, 1983, 1983a) to needle electrodes was based on the character of the studies, where the general activity of the anterior temporal and masseter muscles was essential, not the activity of single or few motor units. The prevalence of mixed types of fibres in different parts of the elevator muscles (Eriksson, 1982) also motivates the choice of surface electrodes. As surface electrodes record the activity from a larger area than do needle electrodes, they pick up more potentials during weak effort (Moller, 1966). The amplitude of these potentials varies less than when using needle electrodes due to the amplitude-distance relationship (Buchta, Guld & Rosenfalck, 1957). Furthermore, surface electrodes seem not to create pain and psychological effects in the subjects, interfere less with natural function, and the mean amplitude recorded varies almost linearly with the force generated at constant length, or during contractions with constant velocity (Milner-Brown & Stein, 1975).

The distance between the surface electrodes, their placement and size were kept constant since the mean voltage varies with these parameters (Moller, 1966). By palpitation of the muscles the electrodes were placed parallel to the main direction of the muscle fibres. When using bipolar surface electrodes with a small interelectrode distance, compared to the size of the muscle, the activity conducted from adjacent muscles is nearly identical on the two leads and therefore rejected (Moller, 1966). Provided a similar electrode position is used, a similar powerspectral distribution curve may be produced when recording one month later as reported by Naeije & Zorn (1981).

Goldensohn in Electromyography (Chapter 11 from the text Disorders of the Temporomandibular Joint) further confirms the preference for recording EMG activity with surface electrodes in cases of TMJ studies.

Goldensohn, M.D., also states, In the electromyographic studies conducted thus far, the majority of patients tested complaining of facial pain and mandibular dysfunction showed recordings different from that of asymptomatic individuals. This suggests a fruitful field for further investigation utilizing surface electrodes

Goldensohn, E. Electromyography. From Disorders of the Temporomandibular Joint Lazlo Schwartz, ed. W.B. Saunders Co., Philadelphia/London. pp. 163-176, 1966.

CHOICE OF ELECTRODES

The choice of electrodes for recording depends upon the specific problem at hand. For temporomandibular joint studies it is best, when possible, to use surface electrodes on the skin overlying the muscle because such electrodes do not cause pain or interfere significantly with joint function

DISCUSSION

Unlike other parts of the body where maximum muscle tension is usually achieved by exerting force against the external environment, the jaw muscles can build up considerable tension from within through the contact of the teeth during clenching or gnashing

In the electromyographic studies conducted thus far, the majority of patients tested complaining of facial pain and mandibular dysfunction showed recordings different from that of asymptomatic individuals. This suggests a fruitful field for further investigation utilizing surface electrodes and ink writing equipment.

Lloyd, in a study at the U.S. Army Medical Research Laboratory, emphasizes the value of using electromyography as a representational measure of neuromuscular activity. The use of surface electrodes for obtaining composite recordings of multiple motor units is described.

The preferability of bipolar surface electrodes to document motor unit recruitment (muscle contraction) is clearly delineated in the study. The use of EMG to evaluate maximal motor recruitment is strongly endorsed by the author's findings. Special note should be made of the thesis proposed regarding reasons for loss of recruitment ability following sustained maximal bite. The multiple causalities further support clinical neuromuscular protocols and procedures.

Lloyd, A. J. Surface electromyography during sustained isometric contractions. *J. Applied Physiology*, 30: 713-719, 1971.

ABSTRACT

Ten volunteers were asked to maintain isometric contractions involving elbow flexor muscles as long as possible at levels equal to 30, 50 and 70% of their maximum voluntary strength and to report when they experienced five successive levels of pain resulting from the contraction. Surface electromyographic recordings were made on the biceps muscle as well as three peripheral muscles. The results indicated that the maximum duration of the contraction could be reliably predicted from the reports of mild and moderate pain intensities

Studies of human physical performance have shown it increasingly profitable to incorporate the electromyogram (EMG) as a representational measure of neuromuscular activity. Typically, surface electrodes are placed directly over the active muscle for recording EMGs during strenuous work. The resulting EMG is a composite recording of numerous motor Units within a relatively large muscle area. A number of studies have demonstrated that a consistent relationship is obtained between the level of recorded EMG activity and such measures as increased isometric contractions, increased tension levels, and maximum endurance times (Bigland & Lippold, 1954; Close, 1964; Eason, 1960; Inman et al., 1952; Wilcot & Beenken, 1957). When EMG activity has been compared with the levels of tension produced by increased isometric contractions, a positive relationship was obtained (Inman et al., 1952). This relationship has been confirmed by studies in which the EMG activity has been represented in digital form by an integration procedure (Wilcot & Beenken, 1957), and by a count of the EMG spikes (Close, 1964). Both procedures appeared to be highly related and demonstrated that as the force of a muscle contraction increased, the level of EMG activity concomitantly increased.

It has been determined that surface EMG activity is a composite of the activity of a relatively large number of motor units even with a moderate contraction. Therefore, an assessment of the frequency and amplitude change in individual motor units. The purpose of the present experiment was to investigate the basis for the increase in EMG activity during maximally sustained isometric contractions.

METHODS

Bipolar recordings of EMG activity were obtained with silver-silver chloride surface electrodes.

DISCUSSION

Surface EMG recordings during strenuous work endurance seemed to provide considerable information about muscle activity. Amplitude increase resulted from a shift in motor unit activity - a shift from random firing of motor units in the unfatigued muscle to synchronized firing in the fatigued muscle. The process appeared to be the same regardless of the contraction force. Synchronization of motor units became the major contributing component for the increased amplitude. The surface electrodes provided a reflection of motor unit activity over a considerable area of muscle tissue and should have adequately represented the activity within the entire muscle (Close, 1964). Amplitude increase could have resulted from either of two previously proposed sources. In terms of the recruitment concept, Olson et al, (1968) determined that, in a passive reflex response, motor units were recruited in an orderly fashion with motor units of smaller amplitudes appearing early. As passive stretch was increased, motor units with larger amplitudes appeared. These results suggested that motor units have varying thresholds which are based on the amount of muscle tension present. Present experimental results suggested that, with the ensuing maximum endurance, there resulted an initial recruitment of higher threshold motor units characterized by a low firing frequency; a similar recruitment process seemed applicable to explain differences in EMG amplitudes at the 30, 50 and 70% contraction forces.

The results of the present experiment suggested that, with an increase in the duration of constant force, synchronization and recruitment produced an increase in the amplitude of the surface EMG. Perhaps, as a constant force was sustained, metabolic reserves were being depleted and the sub-maximum contraction force continued to increase in value until maximum endurance was reached. At this point the force would become the equivalent of 100% maximum and 70% contraction forces where motivation appeared to have less influence on endurance estimations. The frequency shift would accompany the arterial occlusion and potential metabolic depletion from muscle ischemia proposed by Humphreys and Lind (1963). Another alternative could be the resulting compression of the motoneurons, originally suggested by Reid (1928). Either hypothesis was considered feasible on the basis of the present results. Nerve compression, as a source for loss of high-frequency signals in the EMG, could account for the rapid recovery observed after a sustained submaximum contraction. Anabolic and catabolic processes would take considerably longer than recovery functions indicate.

This controlled study of the power-spectra of surface electromyograms of masticating muscles defines the technical and physical parameters of contemporary clinical electromyography. The work of Mitani and Yamashita, at Osaka Dental University, has been pivotal in defining electromyography requirements for a clinical EMG.

Mitani, H., and Yamashita, A. On the power-spectra of the surface electromyograms of masticatory muscles. J. of Osaka Dental Univ., 6: 1-12, 1978.

INTRODUCTION

For the observation of the coordinating style of muscular activity as a whole, from the standpoint of Kinesiology, the surface electromyogram (EMG) is considered particularly well fit for the purpose. In the dental field, also, many reports have so far been made on the participation of the masticatory muscles in holding the position of the jaw, fundamental movement and functional movement of the jaw since Moyers (1950) through an analysis of the surface EMO. In the early stages of research, a subjective analysis only of EMG bursts was performed, but in 1954, Perry and Harris succeeded in plotting the amplitude at 50 msec intervals from high-speed recordings of the EMG and observing the muscle activity quantitatively and qualitatively. Since 1965, Muguruma (1965), Hashimoto (1969) and Tawa (1971) have undertaken to transform the EMG simultaneously recorded from masticatory muscles into integrated curves, and, through the calculation of their areas, clarified the coordination pattern of those muscles at their functional movement.

In this way, since after Piper (1912), in the field of general medicine, first took note of the rhythm of the surface EMG during voluntary contraction, a possibility has been anticipated that the information would be made available concerning the activity of neuromuscular units (through) the frequencies of the EMG. Of late, electronic (instruments) have improved and consequently, an analysis of frequency and correlation has come to be made automatically, and it has become to be known by degrees that information contained in the surface EMG is closely related to the activity of a single NMU

EXPERIMENTAL METHODS

1. Recordings of EMG

The subjects and muscles tested:

Three male youths with normal tooth alignment and occlusion were selected. The muscles and regions tested were the lower middle part of the masseter (Mm), the anterior portion of the temporal (Ta) and the posterior portion of the temporal (Tp) on the left and right sides, totaling six regions. The bipolar disk surface electrodes were placed through the electrode jelly along the muscle fibers on the concerned muscle.

Amplifier and recorder:

A push-pull type EMG amplifier* of which time constant was 0.03 sec was used and the amplification degree was so adjusted that the input signal of 100 (microvolts) would show a 10 mm reflection of the pen. While monitoring by an ink writing oscillograph (at the feeding speed of the recording paper of 50 mm/sec), simultaneous EMG recordings were made at a tape speed of 30 inch/sec on a data recorder.

Contents of the record:

In centric occlusion, which was considered to be the fundamental and most stable position of the mandible, the subjects were instructed to sustain moderate biting for about 3 sec.

Record analyzing equipment and analyzing method:

By using a Real-Time Digital Correlator and Spectrum Analyzer, the EMG obtained under Item 1 above was put to analysis (Fig. 1).

The EMG recorded on the tape was reproduced at 1/10 speed and, through the Correlator and Spectrum analyzer, the power-spectrum was recorded with an Electronic Polyrecorder.

In Tp on both sides the greater part of the spectrum was occupied by a low frequency component (13-30 Hz), without forming a noticeable peak, thus indicating a muscle inactivity (Table 1). In Ta on both sides, a broad spectrum structure was seen, which was 133 Hz and 239 Hz on the right, while, on the left, it was 146 Hz and 239 Hz, respectively forming two perceptible peaks. Both on the left and right, the frequency range was indicated less than about 500 Hz (Table 3).

The power-spectrum of Tp in this case indicated a similarity to that of Figure 2. In respect to Ta, the main frequency component was less than 350 Hz on both sides, a peak being formed on the right, near 160 Hz, while on the left, a multi-peak spectrum structure was seen, a peak being formed at the frequency of 60, 120, 186, 253 Hz. Also, harmonics were presumed to exist, because the frequency at each peak was seen to have a relationship of integers (Table 2). With respect to Mm, a far broader spectrum structure than other muscles was shown both on the left and right, the frequency component being distributed between 13- 630 Hz with no outstanding peak found around 13-320 Hz, indicating a mono-peak spectrum structure with a peak formed at 133 Hz (Table 2). With respect to Mm, the frequency range was 13-400 Hz both on the left and right, indicating a multi- peak spectrum structure on the right, their positions being found approximately on the frequency ranges obtainable by multiplying by integers (e.g., 60, 120, 186 and 226 Hz) (Table 3).

Thus, the frequency components (observed) when a moderate biting was sustained in the centric occlusion were seen to be about 13-600 Hz in Mm and Ta, and somewhat less in Tp, being roughly 13-300 Hz, Tp being known to be more or less inactive than the other two muscles. A rather indistinct peak was seen adjacent to 50-60 Hz and when the power was somewhat increased, an (additional) indistinct peak formed near 146 Hz. On the other hand, in respect to Mm, the main peak was found between 120-150 Hz, the peaks were formed near 50 Hz, 200 Hz, 300 Hz and 400 Hz, indicating a multi-peak structure, which implied the greatest activity. Ta, as the fundamental form of a pattern of normal distribution centering around 133 Hz, showed 2 or 3 minor peaks before and after it. Thus, insofar as the power-spectrum pattern of Ta is concerned, it was seen to be positioned midway between Tp and Mm or rather nearer to Mm.

DISCUSSION

The method of studying the analysis of the frequency distribution of the surface EMG may be classified roughly into (the following) categories:

- [1] Method of mathematic analysis
- [2] Analysis employing the optical method
- [3J] Band width analysis
- [4] Successive short range spectrum analysis
- [5] Correlation analysis.

Any of these methods may be used in accordance with varying objectives. However, not many reports on the study regarding the frequency analysis of the surface EMG are mad in the dental field, quantitative determination having so far been made of the EMG burst in the light of the amplitude values of the original wave. The present study was made (in order) to explore the activity of muscles, quantitatively and qualitatively, in the light of the frequency distribution of the surface EMG of the masticatory muscles through a correlation analysis.

Regarding the relation of muscle contraction and the surface EMG, Inman (et al., 1952), Lippold (1952) and others have reported that a rectilinear relationship exists between the power of the muscle contraction and the integrated value of the EMG in the case of isometric contraction. While, in reference to the frequency spectrum, Sato & Tsuruma (1967) and Hayes (1960) have reported that the frequency spectrum should be constant in the case of contraction stronger than moderate.

As a result of moderate biting sustained in the centric occlusion the present authors were led to presume the following, in the light of the frequency distribution and the power values of EMG of temporal and masseter muscles:

- [1] On the power values and distribution of frequency

As the power value of muscle grows larger, the frequency range of powerspectrum expands and the main frequency component of spectrum is known to shift to a higher range. The surface EMG is known to be a collection of NMU activities and when the muscle is in a state of normal contraction, the synchronous activity of NMU becomes low, each NMU apparently having a disorderly activity. The extent of contraction, strong or weak, depends on the number of NMU joined and the frequency of NMU spikes. In case the power value is large, the number of NMU participating in the activity and the frequency range of their spikes increase, and through temporal and spatial summation, the frequency range of spectrum expands and the high frequency component is assumed to be dominant.

[2] On the formation of higher harmonics

In the case of multi-peak spectrum pictures as seen in left Ta of Fig. 3, and right Mm of Fig. 4, the peaks were seen to be in approximately integer-multiplied frequency ranges. In voluntary biting as performed in the present experiment, the impulse from the pyrimidal tract participates in the firing of the motoneuron of the jaw elevators. By those impulses from the upper center of the brain, the excitatory postsynaptic potential caused in the alpha motoneuron reaches a critical level and discharges an efferent impulse towards the muscle, inviting contraction. It is known that EPSP causes a temporal and spatial summation, and there is a constant relationship of integer multiplication between the firing of the motoneuron and presynaptic impulse (Homma et al., 1970). While Fex and Krakau (1958) reported that the surface EMG is composed of the fundamental wave of NMU cycle of discharge and higher harmonics. If the peak at 60 Hz is considered to be the fundamental wave among the peaks at 60, 120, 186, and 226 Hz (Fig. 3,4), the idea expressed by them appears to be in perfect agreement with the results of the present study. Samejima (1971) likewise agrees that the high frequency component of auto-power-spectrum of the surface EMG has higher harmonics at a frequency corresponding to the cycle of discharge of NMU spikes of the motor unit system. He explains, however, that such correlation is of extremely low extent and from this, the power-spectrum of this sort is assumed not likely to appear frequently.

SUMMARY

The surface EMG of the bilateral middle part of the masseter muscle and of the anterior and posterior portion of the temporal muscle of three young male subjects with normal tooth alignment and occlusion was recorded on magnetic tapes. Then, the recording thus obtained was reproduced, and, through a digital correlator and spectrum analyzer, a power-spectrum was obtained.

In their recent, carefully controlled study at (State University of New York, Buffalo) Burdette and Gale confirmed the replicability and reliability of surface EMG.

Burdette, B.H., and Gale, E.N. Intersession reliability of surface electromyography. Journal of Dental Research, Abstract No. 1370, Volume 66, 1987.

The purpose of this experiment was to compare EMG data from trials both within the same session without moving the electrodes, and between sessions two weeks apart. A custom plastic template was used to reproduce electrode placement sites as closely as possible the second visit.

Seventeen TMD patients were instructed to swallow water and then sit quietly without swallowing for 30 seconds. During this time, EMG data was gathered from the masseter and temporalis muscles on their pain side using 4 bipolar surface electrodes. Three 30-second trials were run and the data analyzed from the last two. This protocol was repeated in two weeks. Head posture was also standardized between sessions.

Correlation coefficients were calculated for each muscle between trials both within sessions and between sessions. The r values ranged from .6584 to .9852 between trials within the same session for both muscles. The r values for the masseter muscle ranged for .6112 to .6671 between trials separated by the two-week interval. Intersession values for the temporalis muscle ranged from .2624 to .3261. Using the standardization technique described, replicability of surface EMG data between recording sessions was considered satisfactory for the masseter muscle.

**STUDIES THAT DOCUMENT THE STATISTICAL COMPARISON OF QUANTITATIVE
ELECTROMYOGRAPHY FROM THE MASTICATORY MUSCLES OF THE “PATIENT”
POPULATION TO THAT OF THE “NORMAL” POPULATION**

In a detailed and controlled study of 36 healthy subjects at the Royal Dental College of Copenhagen in 1966, Moller investigated the maximal bite EMG activity of healthy subjects when they clenched in the intercuspal position.

Moller, E. The chewing apparatus: An electromyographic study of the action of the muscles of mastication and its correlation to facial morphology. Acta Physiologica Scandinavica, Vol. 69, Supp. 280, 73-74, 1966.

Table 25

Average level of the mean voltage in the elevator muscles during maximal bite in the intercuspal position (36 subjects).

Muscles	Ant. temporal	Post temporal	Masseter
M +or- SE uV	257 +or- 13	170 +or- 10	224 +or- 17
SD uV	78	60	102

M: average; SE: standard error; SD: standard deviation.

In a controlled study of quantitative electromyography (Department of Electromyography, Royal Dental College, Copenhagen), Lous et al. measured the postural EMG activity of 39 patients and compared the results against 45 normal subjects. The study relates the quantitative electromyography of masseter and temporalis muscles with mandible at rest to functional disorders of the temporomandibular joint and muscles of mastication, and establishes normative EMG data.

Lous, L, Sheikholeslam, A., and Moller, E. Postural activity in subjects with functional disorders of the chewing apparatus. *Scand. J. Dent. Res.*, 78: 404-410, 1970.

ABSTRACT

In 39 patients with functional disorders of the temporomandibular joint and the muscles of mastication and in 45 dental students without such disorders, the activity in the temporal and masseter muscles was recorded with the subjects seated upright and the mandible at rest. On the average, the level of postural activity in the patients was significantly stronger than in the control group. The increase was not a general trait including all muscles under study, as its location differed among patients and was limited to single muscles in most cases. In the temporal muscles, increased activity was associated with tenderness by palpation. Strong postural activity in the masseter muscles was associated with pain in the cheek and tenderness of the deep part of the muscle, the individual variation of the electromyographic findings pointed to a differentiated etiology more than to a general increase of activity for emotional reasons.

This report gives the preliminary results of a quantitative electromyographic study of oral function in such patients and a statistical comparison with the activity in normal subjects. It deals with the postural activity in the temporal and masseter muscles and the aim was to investigate the concept of hyperactivity or muscle spasms and to relate the electromyographic and clinical findings.

MATERIAL AND METHODS

SAMPLE OF PATIENTS

The patients were chosen at random among those referred to the Royal dental College in Copenhagen for the treatment of functional disorders. The sample included 30 females and 9 males, 14-70 years of age, and majority (22) were 14-24 years old.

SAMPLE OF CONTROLS

A group of dental students were selected: (1) without history of reduced mobility, clicking in the joints, or pain in the joints and the muscles of mastication, and (2) in whom no signs of functional disorders were revealed in the clinical examination. The sample consisted of 19 females and 26 males, 20-30 years of age.

ELECTROMYOGRAPHY

In the recordings with the mandible at rest the level of the mean voltage was measured at intervals of 1 sec; the postural activity in each muscle was characterized by the average of 40 single observations.

RESULTS

A comparison between average findings showed that the postural activity in patients with functional disorders was significantly stronger than in dental students without such disorders; this observation included all muscles under study except the right masseter (Table 2).

DISCUSSION

It emerged that the average level of postural activity in the temporal and masseter muscles was raised significantly in the patients as compared to the control sample

In our sample of patients electromyographic observations were only related to clinical findings in the muscles under study. Increased postural activity was associated with tenderness and in the case of the masseters, pain in the cheek as well.

In a carefully controlled 1971 study of quantitative EMG supported by a grant from the Danish Dental Association, Moller et al. replicated the results of Lous (1970) by studying the masseteric and temporal activities of 24 patients and 45 normal subjects. The findings indicated significant differences in the two groups. Such significant difference was evident even when relaxation was induced in patients and normal subjects. The study documented the variability of EMG resulting from various postural positions.

Moller, E., Sheikholeslam, A., and Lous, L. Deliberate relaxation of the temporal and masseter muscles in subjects with functional disorders of the chewing apparatus. *Scand. J. Dent. Res.*, 79: 478-482, 1971.

ABSTRACT

The ability to relax the temporal and masseter muscles was tested in 24 patients with functional disorders of the muscles of mastication and the temporomandibular joints and in 45 dental students without such disorders. In spite of all efforts taken to induce relaxation in the patients, postural activity remained unchanged as long as they sat up, but a change to supine position caused significant reduction of the activity in the temporal muscle. On the return to an upright position these muscles attained their previous level of activity. In the students, deliberate relaxation was limited to the supine position and caused a reduction of the activity in the temporal muscle. Patients with hyperactivity in masseter muscles with the mandible at rest were too few to demonstrate any effect of relaxation, and the absence of effect in the control sample showed that these muscles do not contribute to mandibular posture.

The present study deals with the activity in the temporal and masseter muscles during deliberate relaxation in subjects with and without functional disorders.

MATERIAL AND METHODS

The sample of patients and controls, the clinical and electromyographic methods, and the activity with the mandible at rest have been described previously (Lous, Sheikholeslam & Moller, 1970). In 24 patients (19 females, 5 males, 14-15 years of age) of the total sample of 39 (30 females, 9 males 14-70 years of age), bilateral electromyographic recording from the temporal and masseter muscles were obtained during deliberate relaxation, first in the upright, sitting position with the head supported, then in the supine position.

The level of the mean voltage was measured at intervals of 1 sec and in each muscle the degree of 20 such measurements taken from recordings during two sessions. Data obtained during and after relaxation were compared to the average of the postural activity at the beginning and the end of a session (Lous et al., 1971).

In the control sample (45 dental students, 19 females and 26 males, 20-30 years of age), recordings during relaxation were limited to the supine position.

DISCUSSION

Electromyography permits direct observation of muscle relaxation. In the present study it showed that ability to relax depends on the position of the subject (up-right versus supine) more than on the condition of the muscles (patients versus normals).

It is concluded, therefore, that hyperactivity in the temporal muscle reflects a deviation in the posture of the mandible. In the etiology of abnormal posture, the importance of specific occlusal conditions appears from the influence of unilateral cross-bite on the postural activity in the posterior temporal muscle (Troelstrup & Moller, 1970). Since the masseter muscles are unaffected by posture, we assume that the cause of tenderness and hyperactivity (with the mandible at rest) in these muscles must be sought in functions involving stronger activity and tooth contact (chewing, swallowing, subconscious grinding and clenching). Such a differentiation between the temporal and masseter muscles could explain why tenderness was observed equally often in both muscles (Lous et al. 1970, Table 1), although increased postural activity was most pronounced in the temporal muscle.

In a controlled study of quantitative EMG at Karolinska Institutet in Sweden, Sheikholeslam compared the EMG resulting from the maximal bite of 39 patients with functional disorders against 45 normal subjects. The authors found significant statistical differences between the maximal bite activity of the patient group in comparison with the maximal bite activity of the control group.

The statistical difference was still significant ($P < 0.05$) even when comparisons of female patients to female controls and male patients to male controls were made. Although the absolute values were smaller in the older patients, reduction by age was insignificant. The "normal" ranges of EMG during maximal bite were established for the temporalis and masseter muscles.

The study established a strong rationale for using EMG during maximal clench to distinguish normal from abnormal masseter and temporalis function. The findings of the controlled study further validates the rationale for EMG maximal motor unit recruitment testing to quantitate muscle status in the clinical environment.

Sheikholeslam, A., Moller, E., and Lous, L. Pain, tenderness and strength of human mandibular elevators. Scand. J. Dent. Res. 88: 60-66, 1980.

ABSTRACT

In terms of the mean voltage during maximal bite in the intercuspal position we compared the strength of the temporal and masseter muscles of 39 patients with functional disorders of the chewing apparatus and 45 controls. Maximal electrical activity was significantly stronger in the controls than in the patients. Differences between the two samples with respect to sex, age, number of opposing teeth in contact and the presence of pain and tenderness tended to favor stronger activity in the controls. However, the different levels of electrical activity, especially in the case of the masseter muscles, could only be accounted for on the basis of a difference in maximal strength. We suggest that the weaker elevator muscles of the patients was a predisposing factor making these muscles less fit to endure hyperactivity induced psychologically or as a reflex response to occlusal interferences and functional disorders of the temporomandibular joints or other elements of the oral neuromuscular system. The sample of controls had much stronger elevators, less susceptible to such hyperactivity.

Maximal strength in human muscles is positively correlated to the diameter (Ringquist, 1973, masseter muscles) and content of type II fibers (Tesch & Karlsson, 1978; Thorstensson et al., 1976; limb muscles). Exercise improves maximal strength (Saltin et al., 1976; Thorstensson, Hulten et al., 1976; limb muscles in man) and may cause an increase of the number of muscle fibers by splitting.

The present study deals with the strength of the temporal and masseter muscles in patients with pain and tenderness of these muscles as compared with a group of controls. Based on the linear relationship between electrical and mechanical muscle activity during isometric contraction (e.g. Lippold, 1952; Milner-Brown & Stein, 1975; Moller, 1966) muscle strength was assessed indirectly by electromyography. The aim was to explore the significance of muscle strength per se as a predisposing factor in the development of pain and tenderness in the muscles of mastication.

MATERIAL AND METHOD

MATERIAL

The patients were questioned with respect to mobility of the mandible, clicking from the temporomandibular joints and the location of their pain. The clinical examination included measurement of the maximal opening movement, auscultation of the joints, and palpation of the joints and the muscles of mastication.

ELECTROMYOGRAPHY

Electrical muscle activity was picked up bilaterally with bipolar surface electrodes over the anterior and posterior temporal and masseter muscles, and the electromyograms and their mean voltages were recorded simultaneously (Troelstrup & Moller, 1970).

The activity during maximal bite in the intercuspal position was recorded during contractions of about 1 second. The degree of activity was assessed in terms of the average level and the peak of the mean voltage (Bakke and Moller, 1980).

RESULTS

The average level and the peak of the mean voltage during maximal bite in the intercuspal position was significantly stronger in the sample of controls than in the patients (Table 2).

Comparing female patients to female controls and male patients to male controls, maximal activity was still significantly stronger in the controls (Table 3).

Although absolute values were smaller in the older patients, reduction by age was insignificant (Table 4).

DISCUSSION

Therefore, the highly significant difference between patients and controls in our study of maximal electrical activity points to a difference with respect to maximal strength.

Since the maximal attainable strength depends on fiber-type characteristics (Ringquist, 1973; Thorstensson, Grimby & Karlsson, 1976; Thorstensson, Hulten, Dobein & Karlsson, 1976; Tesch & Karlsson, 1978), which are partly determined genetically (Komi, 1977) the disposition for functional disorders of the muscles of mastication must vary individually. Therefore, measurements of the strength of these muscles in patients may be a guide to the level of accuracy to which a particular occlusion should be adjusted. The strength-pain relationship also points to muscle exercise as an alternative measure to eliminate muscle pain and tenderness.

In another carefully controlled study using 37 patients before and after treatment of functional disorders of the masticatory system and 43 control subjects the authors demonstrated reduction of postural activity and of symptoms and signs in all muscles under study. In both muscles, reduced activity was accompanied by less pain and tenderness - - most significantly in the masseter. The joint study at Karolinska Institutet and Royal Dental College concluded that "maximal activity in the right and left anterior temporal and masseter muscles became more symmetrical due to treatment," and that "increased postural activity and pain coincide for the muscles of mastication and that pain decreases with activity in response to treatment".

This large-sample, controlled study makes evident the fact that the clinical application of EMG is a valuable quantitative modality for the clinician to measure progress and effectiveness of his therapy, by monitoring EMG postural activity of the anterior temporalis and masseter muscles.

Sheikholeslam, A., Moller, E., and Lous, L. Postural and maximal activity in elevators of mandible before and after treatment of functional disorders. *Scand. J. Dent. Res.*, 90: 37-46, 1982.

ABSTRACT

In a longitudinal study we compared clinical data on pain and tenderness and electromyographic recordings of postural and maximal activity from 37 patients before and after treatment of functional disorders of the masticatory system. Forty-three dental students served as controls. Treatment was followed by a concomitant decrease of pain, tenderness and postural activity. Following treatment, loading in patients decreased significantly and became more symmetrical in the anterior temporal muscles since treatment involved correction of the occlusion we conclude that the intermaxillary conditions of tooth contact during function play a role in the etiology of functional disorders and that the reduction of the relative postural loading of the elevators of the patients due to this treatment contributed to their relief. The relatively high percentage of full effort displayed as postural activity by the patients even after treatment may explain fluctuation of symptoms and signs of functional disorders of the masticatory system. It also emphasizes the need for improved methods of treatment to reduce the probability of recurrence.

If abnormal muscle activity is a source of pain in functional disorders of the masticatory system, treatment followed by the relief of pain must involve changes in the action of the muscles of mastication. Jarabak (1956), Perry (1957) and Ramfjord (1961) have repeated their electromyographic recordings after treatment and, based on observation of the electromyograms, they concluded that occlusal adjustment eliminated the spasms observed in the pre-treatment recordings.

MATERIAL AND METHODS

The present study was based on 37 patients, 28 females and nine males, aged from 14 to 62 (mean 29) years at the time of initial examinations

TREATMENT PROCEDURES

Different types of occlusal splints were used in 23 patients; occlusal adjustment was the sole treatment in 20 patients and was used after previous splint therapy in 14. Exercise, heat and infiltration with local anesthetics was administered as an adjunct to occlusal adjustment or splint-therapy in 17 patients. In one patient temporary correction of oral function was followed by 3-4 years of orthodontic treatment.

EFFECT OF TREATMENT

Treatment was evaluated with respect to improvement of symptoms and signs in the different regions of the masticatory system (Table 1). Pain was reduced by 60% (temple) to 90% (ear), mobility was improved in seven of 10 patients (70%), and joint sounds eliminated in 19 of 29 (66%). Tenderness was reduced by 70% in the temporal and masseter muscles and by 80-85% at the temporomandibular joints. Maximal opening was restored to normal in six of nine subjects (67%) after treatment. Finally, in 25 subjects with joint sounds assessed by stethoscopy before treatment, movements could be performed without such sounds after treatment in 14 patients (56%).

The statistical analysis included average differences between paired observations (pre- and post-treatment) of muscle activity and clinical findings evaluated by Student's t-test.

RESULTS

POSTURAL ACTIVITY

On average occlusal adjustment resulted in a reduction of postural activity and of symptoms and signs in all muscles under study (Table 2). In the anterior temporal muscles, activity decreased by 1.5-2 (microvolts) ($P < 0.01$). In both muscles the reduced level of activity was accompanied by less pain and tenderness, most significantly in the masseter muscles.

DISCUSSION

MAXIMAL ACTIVITY

During isometric contraction electrical and mechanical activity of muscle are linearly related (e.g. Milner-Brown & Stein, 1975; Moller, 1966). Furthermore, action of the elevators of the mandible during maximal bite in the intercuspal position represents the upper limit of the activity during chewing and biting (Moller, 1966) and the maximal force of clenching (Steenberghe & de Vries, 1978). It therefore seems justified to use the average of the mean voltage in the mandibular elevators during maximal bite as a measure of the strength of these muscles. Comparison showed that treatment did not affect muscle strength per se and consequently that subjects with weak muscles are more susceptible to pain and tenderness due to overload than are subjects with strong elevators (cf. Sheikholeslam, Moller & Lous, 1980). However, maximal activity depends on the number and evenness of the distribution of occlusal contacts (Bakke, Moller & Thorsen, 1980) this could be ascribed to the occlusal adjustment.

POSTURAL ACTIVITY RELATIVE TO FULL EFFORT

The present study has demonstrated that increased postural activity and pain coincide in the muscles of mastication and that pain decreases with activity in response to treatment.

It was justified to consider the postural activity in our patients and controls as a sign of continuous contraction. In the patients before treatment and associated with pain the level of activity in the temporal and masseter muscles was more than twice that of the controls (cf. Table 4). In response to treatment, postural activity of the patients on average decreased by 30% in the anterior temporal muscles ($P < 0.01$) and 20-25% in the posterior temporal and masseter muscles ($0.05 < P < 0.10$). We suggest that the significantly lower incidence of pain after treatment was due to this reduction of postural activity.

Our study has demonstrated a significant reduction of pain and or the relative postural loading of the anterior temporal muscles (cf. Table 4). A tendency of a similar reduction in the posterior temporal and masseter muscles was observed. However, in all three pairs of muscles the proportion of full effort displayed as postural activity in the patients after treatment was still significantly above the controls. The smaller strength of the elevators in patients as compared to controls may in part explain why the patients had to activate a larger part of their muscles to support the mandible. This difference made the elevators of the patients more susceptible to overload and we hold it responsible for the long and short term fluctuation of symptoms and signs of functional disorders (Kopp, 1977). The relative excess of postural activity in patients after treatment also emphasizes the need for improving the methods of functional correction in order to diminish the probability of recurrence of pain and tenderness.

In a controlled electromyographic study of mastication in 37 patients and 43 control subjects, Moller, et al., demonstrated that by analyzing the EMG values from the muscles of mastication, parameters of muscle coordination are studied and a quantitative measurement of hyperactivity during mastication is determined." Relative strength and relative contraction time differed between patients and controls. Differences between controls and patients with respect to relative strength and contraction times concerned all muscles under study, and improved significantly after successful treatment.

Moller, E., Sheikholeslam, A., and Lous, L. Response of elevator activity during mastication to treatment of functional disorders. *Scand. J. Dent. Res.*, 90: 37-46, 1984.

ABSTRACT

The pattern of elevator activity during mastication in temporal and masseter muscles of 37 patients with functional disorders and pain in the masticatory system was studied before and after conventional treatment and compared with a control group of 43 subjects. As compared to controls, patients before treatment chewed with greater relative strength (percent of maximal elevator activity), longer relative contraction times (percent of total duration of chewing cycle) and stronger intermediary activity between strokes. These parameters of muscle coordination are proposed as quantitative estimates of "hyperactivity." Conventional treatment abolished pain, tenderness and other symptoms and signs completely in 18 patients in whom the most significant findings in the muscles under study were reductions in absolute and relative contraction times ascribed to increased stability produced by occlusal adjustment. It is suggested that relatively shorter pauses before treatment impaired blood flow and that their prolongation following treatment improved circulation. During the strong, dynamic contractions of mastication, masseter muscles tended to be more susceptible to hyperactivity than the temporal muscles.

We have previously demonstrated coincidence of increased postural activity, pain and tenderness of elevators of the mandible and simultaneous decrease of this activity and of pain and tenderness after treatment (Sheikholeslam, Moller & Lous, 1982)

DISCUSSION

PAIN AND ITS RELIEF

The present study introduces two quantitative parameters of "hyperactivity" during mastication: relative strength and relative contraction time which both differed between patients and controls

Differences between controls and patients with respect to relative strength and contraction times as well as reduction of contraction times, absolute and relatively, after successful treatment concerned all muscles under study. However, the number of time parameters differed and the levels of significance were most pronounced for the masseter muscles. Hyperactivity in terms of relatively increased postural activity has also been shown and included all muscles under study (Sheikholeslam, Moller & Lous, 1982), but the most substantial differences concerned the temporal muscles. Hence, the temporal muscles tend to be susceptible to static overload while the masseter muscles are most likely to acquire their symptoms and signs of overload during the strong, dynamic contractions of mastication.

In a well controlled study of EMG activity in normal subjects and in patients with a history of chronic pain, Cram, et al. monitored the EMG levels of 10 muscle groups, first in the sitting and then in the standing posture.

The EMG study verified that in the sitting position, the patients exhibited significantly different postural activity than that of nonpain control subjects in the temporalis and the masseter muscles. The authors concluded that "the general findings of this descriptive study clearly suggest that the muscle activity of pain patients is different than that of nonpain subjects." Because of their large number of nonpain subjects in this study (N=104), the investigators established a carefully collected normative data base for normal subjects.

Cram, J.K., and Engstrom, D. Patterns of neuromuscular activity in pain and nonpain patients. Clinical Biofeedback and Health Vol. 9, No.2, pp. 106-115, 1986.

The purpose of this study was to compare the patterns of surface EMG activity in normal subjects and in patients with a history of chronic pain. Surface EMG activity was sampled from the right and left homologous sites of ten muscle groups, first in the sitting and then in the standing posture. Statistical comparisons between the normal subjects (N=104) and chronic pain patients (N=200) were conducted on each of the 40 sources of surface EMG data. The results of the study indicate that chronic pain patients exhibit a higher level of surface EMG activity, with 38 percent of the sampled sites being significantly higher. An asymmetrical pattern of activation is clearly noted in the erector spinae muscles (while standing) for the pain population these findings support previous research indicating abnormal neuromuscular activity and posture in chronic pain patients.

SUBJECTS

The nonpain population consisted of 64 university students and 40 hospital outpatients screened in a general medical clinic for cardiovascular fitness. Prior to this screening, all 104 subjects were questioned about and denied ever being treated for chronic or recurrent pain during the past three years. . . . The mean age of the nonpain population was 29.6 years: 50% were female, 50% were male.

The population of pain patients consisted of 200 consecutive admissions to the chronic pain therapy program at the Swedish Hospital Pain Center.

RESULTS

Each muscle site for each posture was statistically compared using univariate F-tests. Because of the multiple comparisons, a probability value of .01 was used to decide as to the statistical separation of the two groups.

The mean and standard deviations for the two populations may be seen in Table 2. In all instances, a significant difference between the two populations represents a greater amount of activation of the muscles for the pain patients.

DISCUSSION

The general findings of this descriptive study clearly suggest that the muscle activity of pain patients is different than that of nonpain subjects.

This study identifies an objective diagnostic protocol by using EMG when comparing the postural activity and the maximal activity of the mandibular muscles against the normal ranges stored in a computer data base. Michler, et al. (Royal Dental College and University of Alborg, in Denmark) used EMG to differentiate between normal subjects and patients exhibiting functional disorder of masticatory system.

Michler, L., Moller, E., and Bakke, M. On-line analysis of natural activity in muscles of mastication. Journal of Craniomandibular Disorders: Facial & Oral Pain, Vol. 2, No. 2: 65-82, 1988.

ABSTRACT

A system for automatic on-line analysis of electromyographic recordings during natural activity in the muscles of mastication has been developed. Acquisition and digitizing of data, their filtering to mean voltage, gain read-off, statistical treatment, and table/graphic presentation of results are in control of a microcomputer. Amplitude and time measurements marked on direct tracings combined with tabulated statistics of the same data permit immediate check of their validity before further calculations. A screen menu directs standard examination reducing control of one pushbutton for start/compute and one for delete. With instant access to parameters of muscle action and appropriate statistics, electromyography is now available for direct functional control during clinical procedures and basic experiments.

1. Resting posture is recorded for 10 seconds with the subject sitting upright without a headrest and with eyes open.
2. Resting posture as in 1, but with eyes closed.

DISCUSSION

A standardized electromyographic examination of natural oral functions with manual, time-consuming acquisition of data and subsequent computer analysis has been employed for several years (Moller, 1966, 1970 and 1974).

Electromyography and Diagnosis: This article deals with the properties of an on-line measuring system opening for quantitative, statistical evaluation of findings in individual subjects versus normal materials available from control groups of previous studies (Moller, E. 1966; Moller, E., Sheikholeslam, A. & Lous, I. 1984; Lous, I., Sheikholeslam, A. & Moller, E. 1970; Sheikholeslam, A., Moller, E. & Lous, I. 1980).

Mean values with a standard deviation derived from that study are in the anterior temporal 3.5 mV, SD 1.7, in the posterior temporal 4.3 mV, SD 2.5, and in the masseters 2.4 mV, SD 0.8 (average of the right and the left side).

CONCLUSION

The present on-line analysis of natural activity in craniomandibular muscles builds on a quantitative method of assessing whole-muscle electromyograms used routinely in clinical and experimental work for more than 20 years. However, the advantages that are obtained by computerizing the procedure are epoch making:

It permits control of the data before they enter the final phase of calculations and offers instant guidance on treatment procedures or experimental set up. Any system with a delay exceeding the time the subject could reasonably be expected to remain available for a recording cannot fulfill this claim.

It limits duration for an extensive functional electromyographic examination to the time of recording. This represents saving 30 to 40 hours of measuring and a delay of about 2 weeks before having statistical data available.

In a controlled study of quantitative electromyography at University of Alberta, Gervais, et al, documented the comparison of the resting EMG levels from masseter and temporalis muscles of the “patient” subjects to that of the “normal” subjects. The 116 subjects in the study were classified into three experimental groups of asymptomatic (no signs or symptoms of TM dysfunction), subclinical (one or few signs or symptoms) and patient (significant signs or symptoms and pain).

The investigators concluded that “the patient group demonstrated significantly higher EMG activity than the asymptomatic or subclinical groups for all variables except the right masseter ($F(3,220) = 6.65, p < 0.001$). These findings strengthen diagnostic and assessment procedures and criteria as well as suggest alternate treatment.” The study’s extensive statistical tests further confirmed that “no sex differences were noted for the patient group, nor was patient age a clinically significant factor.”

Gervais, R.O., Fitzsimmons, G.W., and Thomas, N.R. Masseter and temporalis electromyographic activity in asymptomatic, subclinical, and temporomandibular joint dysfunction patients. The Journal of Craniomandibular Practice, Vol. 7, No. 1, pp. 52 - 57, 1989.

ABSTRACT

For the present study, resting EMG levels for each masseter and temporalis were obtained from three groups of subjects: asymptomatic (female, $N = 24$, mean age = 26.4); subclinical (female, $N = 31$, mean age = 28.6); and patient ($N = 61$, female 70%, mean age = 31.9). A Biocomp 2001 biofeedback system was used to gather the EMG data from each of the four sites during a six- to eight-minute resting baseline period. The patient group demonstrated significantly higher EMG activity than the asymptomatic or subclinical groups for all variables except the right masseter ($F(8,220) = 6.65, p < 0.001$), the temporalis was found to be the site of greatest EMG activity more frequently than the masseter. These findings strengthen diagnostic and assessment procedures and criteria, as well as suggest alternate treatment and research protocols.

METHOD

The 116 subjects for this study were classified into three experimental groups: asymptomatic, subclinical, and patient.

All respondents were subsequently asked to complete a TMJ symptom questionnaire in order to determine group membership. The subclinical subjects were selected on the basis of a “yes” response to any of the symptoms in addition to facial or TMJ pain, or joint noises.

The selection of the asymptomatic subjects proceeded in a similar manner except that none could have positive signs or symptoms of TM dysfunction.

The patient group was comprised of 61 consecutive TMJ patient referrals directed to the author’s practice.... Forty-three (70%) were female (mean age 33.8), and 18 (30%) were male (mean age 31.2).... Demographically, the patient group was consistent with the epidemiological literature which reports that 65% to 80% of clinical patients are female, and predominantly between 20 to 40 years of age.²¹

PROCEDURE

The subjects were instructed to maintain a stable relaxed posture with eyes closed and to avoid extraneous movement during the recording periods, which were 6 to 8 minutes in length. No specific instructions to relax the jaw were given as the intent was to assess typical or habitual temporalis and masseter activity.

RESULTS

The null hypothesis of no difference in group means was tested and rejected using multivariate analysis of variance procedures (MANOVA). Significantly greater mean EMG levels were noted in the patient group as compared to the asymptomatic and subclinical groups, $F(8,220) 6.65, p < 0.001$.

Simultaneous confidence intervals for each of the four variables revealed that the patient group differed significantly, at the 95% confidence level, from the asymptomatic and subclinical groups on all variables except the right masseter.

A Hotelling's T² analysis of the patient group EMG levels was also conducted on the basis of sex. No significant differences between male and female subjects were noted, $F(4, 56) = 0.85$, $p = 0.49$.

DISCUSSION

In this study, three groups of subjects comprising asymptomatic, subclinical, and TM dysfunction patients were contrasted with respect to resting masseter and temporalis EMG levels. The patient group was found to have significantly greater resting muscle activity on three of the variables: left and right temporalis, and left masseter. No sex differences in muscle activity were noted for the patient group, nor were patient age a clinically significant factor.

The findings of this study suggest that for both female and male TMJ patients, resting EMG levels of 2 [microvolts] with a standard deviation of 1 [microvolt] indicate normal temporalis or masseter activity. Conversely, in assessing the appropriateness of biofeedback training, the presence of a neuromuscular component in the condition would be indicated by mean resting EMG of 5 [microvolts] with a standard deviation of 4 [microvolts] in one or more of the masseters or temporalis. A positive correlation would be expected between the magnitude of EMG activity and the severity of the reported clinical signs and symptoms.

In a treatment protocol based on the normative indications, the therapeutic goals would focus upon reducing the presenting neuromuscular hyperactivity for all four muscle sites to normal or subclinical levels, at which point the muscle-related symptoms should resolve.

STUDIES THAT DOCUMENT THE DIAGNOSTIC EFFICACY OF ELECTROMYOGRAPHY IN DENTISTRY

In this well-known study, Moller (the head of the Department of Electromyography, Royal Dental College, Copenhagen), states that, "Electromyography of the activity during full effort is an important supplement to the clinical examination of the muscles of mastication." This conclusion further verifies the rationale for the standard EMG function clinical protocol. Moller also concludes, "Electromyography provides an objective means of deciding the degree of predominance of one side during natural chewing."

The author concludes: "The functional analysis includes the muscular activity at rest and during full effort, chewing and swallowing; it requires quantitation of the electromyograms and statistical evaluation of the findings. As a supplement to the clinical and radiological investigation, electromyography can contribute to a more precise diagnosis of functional disorders of the chewing apparatus and of the importance of function in malocclusion."

Moller, E. Clinical electromyography in dentistry. *Int. Dent. J.*, 19: 250-266, 1969.

INTRODUCTION

Electromyography is the recording of muscle action potentials. Therefore the electromyogram reflects the degree of motor innervation and gives an indirect measure of the force exerted by the individual muscle as well as the time of its activation.

The aim of the present report is to exemplify electromyography as a diagnostic method in dentistry. Electromyography can be applied clinically in two ways:

1. Findings from intramuscular recordings during voluntary effort can contribute to the differentiation between myopathy and neuropathy; the electromyographic changes include duration, amplitude, and shape of single action potentials, the territory of individual motor units, and the pattern of activity during full effort (Buchthal, 1966).
2. During natural function simultaneous recordings from several muscles can be used to analyze their coordination in time and intensity. In the case of dentistry, functional analyses by electromyography can contribute to a more precise diagnosis of functional disorders of the chewing apparatus and of the importance of function in malocclusion.

TECHNIQUE

The electrical activity of muscles can be recorded intramuscularly with needle electrodes or over the muscles with surface electrodes. For the functional analysis, surface electrodes are applicable to study the action of the temporal, masseter, and orbicularis oris muscles.

During natural function the activity in most instances appears as a pattern of interference. A measure of the amplitude, number and duration of the potential changes of the interference pattern can be obtained by recording its numerical mean voltage, the degree of activity at rest and during full effort (Fig. 1A) is characterized by the average level of the mean voltage.

ELECTROMYOGRAPHIC ANALYSIS OF ORAL FUNCTION

The different functions of the chewing apparatus demand a precise coordination in time and intensity of a large number of muscles. To demonstrate deviations in the patterns of coordination the electromyograms have been quantitated as described and compared with the findings obtained from 36 male dental students published earlier (Moller, 1966). The functional analysis includes the activity at rest and during full effort, chewing and swallowing

POSTURAL ACTIVITY

In subjects complaining of pain in the muscles of mastication or in the temporomandibular joints, the level of postural activity may be increased. A significant rise of the activity in a single muscle is demonstrated by recordings from a full denture subject with pain localized to the left side of the face (Fig. 2B) in the differentiation between causes of facial pain, electromyography can contribute by indicating if and where postural activity is increased.

FULL EFFORT

The clinical importance of recordings during full effort is demonstrated by three cases (Fig. 3, A-C).

In a 15 year old girl referred for electromyography with the diagnosis of hypertrophy of the masseters (A) a swelling over the right masseter had persisted after a parotitis at the age of twelve. The activity recorded during maximal bite in the intercuspal position was 75 per cent less than normal on the right side (pseudohypertrophy) and twice the normal on the left side (hypertrophy). Duration of motor Unit potentials showed no significant difference from the normal. However, the average duration on the right side (8.9 msec) was significantly lower than on the left side (11.3 msec); this finding in connection with the difference between the mean voltages during full effort indicated a localized myogenic affection in the right masseter.

An electromyographic examination of a 47 year old woman with an apparent hypertrophy of the right masseter (B) showed normal level of activity in this muscle during full effort; recordings from the left masseter indicated a 75 per cent decrease. Average duration of action potentials in the right (10.4 msec) and left (9.4 msec) masseter showed no significant deviation from the normal (9.7 msec, standard deviation: 1.0 msec). Conclusion from the electromyographic examination: normal conditions on the right side, reduced number of motor units (atrophy) on the left side.

For a comparison, recordings are shown from a male dental student without clinical signs of hypertrophy of the masseter (C) but with 100 per cent increase of the level of activity on both sides.

Electromyography of the activity during full effort is an important supplement to the clinical examination of the muscles of mastication.

MASTICATION

Identical (symmetrical) innervation of the elevator muscles on the right and left side rarely occurs during natural chewing; in most instances there is a random shift of predominance and the extent and direction of mandibular movements. It is reasonable to assume that consistent predominance of one side can cause pain in muscles, joints and periodontal tissues. In fact, such a relation has been suggested from a clinical survey of 400 patients with disorders of the temporomandibular joints by Boering (1966).

Electromyography provides an objective means of deciding the degree of predominance of one side during natural chewing.

SWALLOWING

The action of the muscles of mastication during swallowing has mainly been considered in relation to malocclusion. Rix (1946), Tulley (1935) and Gwynne-Evans (1954) divided the oral phase during swallowing of saliva into a 'normal' type performed with strong action of the masseter muscles, tooth contact and relaxed lips and an 'abnormal' type without tooth contact and with intense action of the lips.

From electromyographic recordings during swallowing, it is possible to analyze the individual combination of muscle activity, and decide whether it has a compensatory or dysplastic effect on the malocclusion in question.

SUMMARY

The present report deals with the application of electromyographic analysis of oral function as a diagnostic method in dentistry. The functional analysis includes the muscular activity at rest and during full effort, chewing and swallowing; it requires quantitation of the electromyograms and statistical evaluation of the findings. As a supplement to the clinical and radiological investigation, electromyography can contribute to a more precise diagnosis of functional disorders of the chewing apparatus and of the importance of function in malocclusion.

In a controlled study of bite force in a group of patients and normal subjects, Helkimo et al. documented the statistically significant difference in bite force between the two experimental groups. The study at University of Gothenburg in Sweden found that "bite force in the patient group was lower than in the control group at the first registration but increased with palliation of the symptoms during treatment." Since numerous studies have documented the strong positive correlation between electromyography and muscular force (Lippold, 1952; Bigland and Lippold, 1954; Molin, 1972; Milner-Brown, 1975; Prumi, 1978); the following study further supports the diagnostically valid EMG differences between patient groups and controls.

Helkimo, E., Carlsson, G.E., and Carmeli, Y. Bite force in patients with functional disturbances of the masticatory system. *Journal of Oral Rehabilitation*, 2: 397-406, 1975.

SUMMARY

In thirty patients (24 women and 6 men) treated because of dysfunction of the masticatory system at the department of stomatognathic Physiology, University of Gothenburg, bite force was registered before, during and after treatment had been completed. In the controls, thirty-six dental students and trainee dental nurses, with no dysfunction of the masticatory system, bite force was registered on two occasions.

Bite force was measured between the first molars on each side and between the central incisors. Also finger force was registered. The force measurements were made at five different levels, increasing from very weak to maximum force. Repeated tests of bite force in the control group, made at intervals of about 1 week, gave almost identical results. Bite force in the patient group was lower than in the control group at the first registration but increased with palliation of the symptoms during treatment.

In a 1985 study, Myslinksi et al., at the Department of Physiology of Baltimore College of Dental Surgery used EMG to quantify muscle pain in patients suffering from MPD before and after therapy. Using extensive statistical tests, the authors concluded that there was a parallel relationship between objective EMG and perceived pain. When pain attenuated and then returned, the EMG signals followed accordingly. The highest correlation between EMG readings and subjective pain ratings was demonstrated in the resting mode. The authors used multiple regression analysis to quantify the reduction in perceived pain from a proposed mathematical formula. Although the formula relates the change in pain levels using analgesics, the authors contend that the formula is also reliable for mechanical therapeutic techniques.

This study further emphasizes the importance of monitoring postural activity using quantitative electromyography for differential diagnosis of MPD and assessment of treatment progress.

Myslinksi, N. R., Buxbaum, J. D., and Parente, F. J. The use of electromyography to quantify muscle pain. Meth. and Find. Exptl. Clin. Pharmacol, 7(10): 551-556, 1985.

SUMMARY

This study was designed to determine the feasibility of using electromyography (EMG) to quantify muscle pain in patients suffering from chronic myofascial pain dysfunction (MPD). Ten patients were carefully selected to include those having mild to severe pain, but not any major psychological or other physiological dysfunction.

Measurements of perceived pain and EMG frequency and amplitude were recorded before and after standard analgesic therapy. EMG recordings were collected bilaterally from the masseter and anterior temporalis muscles during the resting, swallowing, clenching and chewing modes of activity. Multiple regression (R) analysis indicated that changes in perceived pain are correlated with changes in the EMG and can be determined by using the following formula: $P = (F) (0.405) + C$ where P = perceived pain level, F = EMG frequency, and C = 1.533. By computing the Phi coefficients, the highest correlation between EMG recordings and subjective pain ratings was demonstrated in the resting mode. In this mode, 64% (multiple R = 0.80) of the variance in perceived pain difference scores from pre- to post-therapy tests could be determined.

INTRODUCTION

EMG of the masticatory musculature has been employed as a method of diagnosis and pain assessment in both research and clinical situations (Sheikholeslam, A., Moller, E. and Lous, I. (1982). EMG has been of particular value in the diagnosis and treatment assessment of patients afflicted with MPD syndrome (Buxbaum, J.D., 1982; Mikhael, M., and Rosen, H., 1980). Munro has shown that EMG activity in the masseter and anterior temporalis muscles of patients with MPD is significantly greater than that of normal subjects (Munro, R. R., 1975). In laboratory tests on the patients in this study, we observed that levels of EMG activity appeared to have direct correlation with the subjective pain levels reported by the patients. This relationship is possibly due to a pain-spasm-pain cycle in the masticatory muscles. To evaluate the feasibility of using EMG to quantify muscle pain in these patients, the study was designed with the following questions in mind:

1. Is there a statistically significant correlation between changes in muscle pain and changes in EMG?
2. Which EMG parameter yields the strongest EMG/pain correlation?
3. Which mode of muscle activity yields the strongest EMG/pain correlation?

PATIENT SELECTION

Those that participated in the study were diagnosed as having MPD syndrome with muscle spasm as the major sign. They consist of six females and four males, aged 15 to 41 years, with mild to severe symptoms

EXPERIMENTAL PROCEDURE

Pain and electromyography readings were taken before and after therapy for each subject EMGs were obtained bilaterally with bipolar surface electrodes from both the masseter and anterior temporalis muscle during five modes of activity. Although other muscles may be involved in the pain, more than 90% of patients with MPD have involvement of the anterior temporalis or masseter muscles, or both (Mikhael, M. and Rosen, H. 1980). Subjects were their own controls. They had no knowledge of changes that occurred in their EMG. The investigators that administered the subjective visual scale for pain were different from those who analyzed the EMG.

STATISTICS

Difference scores were computed by subtracting each patients pre- and post- therapy pain, frequency, and amplitude scores.

RESULTS

There was a significant correlation between changes in pain and changes in EMG. They indicate that the most sensitive relationships between EMG measures and pain difference ratings were in the resting mode.

DISCUSSION

The present study attempted to correlate changes in muscle pain with changes in muscle spasm in a select group of patients chosen from MPD patients.

Spasm can be caused by muscle overextension, muscle over contraction, or muscle fatigue These habits can be triggered by such things as improperly occluding restorations, but are most often involuntary tension-relieving mechanisms (Laskin, D. 1969). The work of Christenson supports muscular fatigue as the direct cause of pain (Christenson, L. 1967). He found that prolonged voluntary loading can produce the signs and symptoms of MPD. In a study conducted by Yemm, subjects within a control group were able to relax their muscles between successive attempts at a task, but MPD patients could not relax their muscles between tasks (Yemm, R. 1969). The muscle spasm in MPD is self-perpetuating. The spasm causes pain and muscle tenderness, which in turn causes more spasm. The end result is a spasm-pain-spasm cycle. Bruno, in his work on premature occlusal contacts and masticatory muscle spasm, states that if muscle spasm is allowed to continue pain will result (Bruno, S. 1971). Travell states that when muscles are subject+ to pain they act only in one way: they develop spasm and shorten (Travell, J. 1960).

In the present study, there was a parallel relationship between objective EMG and perceived pain. It showed that the test for the multiple R was statistically reliable. As the pain attenuated after treatment and then returned, the EMG signals followed accordingly in a graded manner. The analgesic therapy breaks the pain-spasm-pain cycle. Eliminating the pain eliminates the muscle spasm.

In this study, the method used to change pain levels was the non-narcotic analgesic, ibuprofen. Other observations in the laboratory indicated that the correlation holds even when using different methods of changing pain levels. Preliminary data suggest that the regression equation is reliable with mechanical therapy to... For example, MPD pain can be alleviated by fitting the subject with a dental appliance to increase vertical dimension, or in other words, change the length of the masticatory muscles so that they are operating in a more optimal range

In summary, the present study has indicated a close correlation between changes in perceived muscle pain and changes in EMG parameters in uncomplicated MPD patients.

In a controlled clinical study in the Department of Physiology at the University of Florence, Pantaleo et al, electromyographically compared the postural activity and maximal activity of patient versus control subjects before and after treatment.

The authors conclude that in control subjects “the EMG analysis did not show any activity either in the masseter or temporalis muscles at rest...”. “The MPD patients showed involuntary muscular activity at rest in the anterior portion of the temporalis muscle...”. “The correction of occlusal position by acrylic splints was able to induce a persistent reduction of abnormal EMG activity at rest and a good relief of pain”.

Maximal (bite) activity of normal subjects “was fast and complete” in contrast to the patients that exhibited “low maximum level that was not maintained”. After occlusal therapy which accompanied improvements in symptoms, the patients showed “higher levels of EMG during maximal biting in the intercuspal position”.

Pantaleo, T., Prayer-Galletti, F., Pini-Prato, G., and Prayer-Galletti, S. An electromyographic study in patients with myofascial pain- dysfunction syndrome, Bulletin Group. Int. Rech. sc. Stomat. et Odont., 26: 167- 179, 1983.

In normal subjects, in an upright position with the lips slightly in contact but the teeth not together, during the voluntary muscle relaxation, there is virtually no activity in the masticatory muscles investigated (Vitti, M. & Basmajian, J. V. 1975 and 1977), except for the subjects with occlusal interferences.

The relationship between the electromyographic (EMG) activity of the masticatory muscles and some types of malocclusion has been investigated by earlier researchers (Moyers, R. E., 1949; Liebman, F. M. & Cosenza, F., 1960; Moss, J. P. & Greenfield, B.E., 1965; Grosfeld, O., 1965; Ahlgren, J., 1966; Ahlgren, J. et al., 1973; Moss, J. P. & Chalmers, C. P., 1974; Moss, J. P., 1975; Pancherz, H., 1980), chiefly regarding temporalis and masseter muscles.

METHODS

The subjects studied were 5 healthy volunteers (3 males and 2 females) aging from 19 to 38 years) and 11 MPD syndrome patients (6 males and 5 females ranging in age from 20 to 42 years). . The EMG activity was studied both at rest and during the maximal biting in the intercuspal position

RESULTS

CONTROL SUBJECTS

The EMG analysis did not show any activity either in the masseter or in the temporalis muscles at rest; (maximal biting in the intercuspal position) was fast and complete.

PATIENTS WITH MPD SYNDROME

The EMG study revealed an involuntary muscular activity at rest in the anterior position of the temporalis muscle in all rested positions

When the occlusion was corrected with acrylic splints the EMG patterns also improved: the involuntary EMG activity greatly decreased and sometimes disappeared after the splint was applied.

All MPD patients displayed abnormal EMG patterns during the maximal biting in the intercuspal position, i.e., the EMG activity during the voluntary contraction increased slowly to a low maximum level that was not maintained (progressive decrease of activity).

After the correction of the occlusal malrelation with splints, EMG patterns improved and appeared more similar to those of control subjects.

DISCUSSION

The decrease of the abnormal EMG activity after the correction of the occlusal malrelation with acrylic splints confirms this interpretation and points out that an occlusal discrepancy can be the cause of an abnormal EMG activity and of the consequent MPD syndrome.

SUMMARY

An electromyographic (EMG) study of ipsilateral masseter and temporalis muscles was undertaken in healthy volunteers and in patients with MPD syndrome, with the aim of getting further insight into the pathophysiology of this disease. Unlike controls, patients had abnormal MKG features and displayed unvoluntary sustained EMG activity at rest, chiefly in the temporalis muscle.

The correction of occlusal position by acrylic splints was able to induce a persistent reduction or a suppression of the abnormal EMG activity at rest and a good relief of pain; moreover, after the correction, higher levels of EMG activity were found during maximal biting in the intercuspal position.

Mechanisms underlying these effects were discussed and in particular it was suggested that abnormal afferent activity from periodontium and jaw muscles may contribute to the establishment of sustained contraction leading to muscular pain, which in turn may cause reflex muscle activity in a vicious circle.

Cooper et al., in a 1986 study of 476 patients conducted at New York Medical College, investigated the symptoms, clinical examination findings, and EMG of postural activity of masseter and temporalis muscles. The authors demonstrated that only 11% of subjects had normal postural activity prior to treatment. Following 3 months of therapy, 88% of subjects reported that improvement or cure of some symptoms had occurred." The improvement in symptoms accompanied reduced postural EMG activity of the masseter and temporalis muscles.

Cooper, B.C., Alleva, M., Cooper, D., and Lucente, F.E. Myofacial pain dysfunction: Analysis of 476 patients. Laryngoscope, 96: 1099-1106, 1986.

ABSTRACT

Myofacial Pain Dysfunction (MPD) is a musculoskeletal dysfunction involving malrelationship among the neuromuscular system, temporomandibular joints, and dental occlusion. The illness affects children and adults of all ages and both sexes. Patients complain of pain and or dysfunction in the mandible, temporomandibular joints, ears, oral cavity, head, and neck. Electronic measurement of mandibular movement and associated muscle function now provide reproducible data with which the parameters of this illness and therapy can be designed and monitored.

In this study, data are presented on 476 MPD patients. Included are statistics on the most commonly occurring symptoms, clinical examination findings, and electronic test data before and following treatment. Electromyography (EMG) is used to analyze the resting status of mandibular muscles and the functioning in the occlusal position.

The data show a positive correlation between the clinical symptoms of MPD and unhealthy mandibular position at occlusion, accompanied by specific unhealthy muscle activity. There is a strong positive correlation between a therapeutic change in the dental occlusion to a neuromuscularly healthy person using a precision orthotic appliance and the relief of symptoms within 1 month as expressed by 88% of the patients. A similar correlation exists at 3 months and long-term.

In this study, data is presented on symptoms and clinical examination findings of 837 MPD patients. With the use of bioelectronic instrumentation, fixed parameters of a single disease entity (MPD) have been established and are used to evaluate patients, design therapy, and monitor results objectively. Electronic test data before and after treatment are presented on 476 patients from the initially examined subject group.

MATERIALS AND METHODS

From 1979 through 1985, 837 patients (661 females and 176 males) between the ages of 7 and 76 were referred for diagnosis of MPD.

A subgroup of 476 subjects underwent complete testing and therapy.

The Electromyograph (models EM1R and EM2) utilizes bipolar surface electrodes to measure the electrical activity in the muscle fibers beneath the electrode. This instrument measures both the resting levels of muscles and their compressive capacity at work in this study, middle masseter and anterior temporalis muscle fibers were monitored.

PHASE I CLINICAL DIAGNOSIS

Following review of a patient's questionnaire, which included a listing of symptoms and history, a clinical examination was performed to determine whether a tentative clinical diagnosis of MPD could be established. Lateral transcranial radiographs of the temporomandibular joints were taken to rule out joint abnormalities.

PHASE II ELECTRONIC DIAGNOSIS

An electromyographic study of electrical resting levels of the anterior temporalis and masseter muscles bilaterally was performed.

PHASE III THERAPY

Within the first 3 weeks after insertion of the appliance, patients returned for adjustments . . . one to three times. They were asked to reevaluate the status of their symptoms 1 month after initiation of therapy.

PHASE IV REEVALUATION AND MONITORING THERAPY

Three months after initiation of treatment, patients were retested with MKG EMG to determine whether the orthotic appliance being worn accurately provided neuromuscular occlusion. Patients, were again requested to compare their current symptoms with their original presenting symptoms.

PHASE V LONG-TERM TREATMENT

Long-term therapy was recommended to perpetuate the neuromuscular occlusion.

RESULTS

After 1 month, 79% indicated that they had experienced significant improvement or cure of symptoms as a result of therapy.

Following 3 months of therapy, 88% of subjects reported that improvement or cure of some symptoms had occurred.

Electromyographic recordings made on the anterior temporalis and middle masseter muscle fibers bilaterally were used to determine the resting status of those muscle groups "Rest" is defined on the EM2 instrument as ≤ 2.5 mV. 17.1% of subjects had 3 of the 4 muscles rested and 11.2% had all four muscles rested.

The treated group of 476 received electromyographic testing which substantiated the hypothesis that almost all individuals attempt to posture their mandibles in an accommodative position. This is done by hyperactivity in the muscles responsible for movement.

The importance of the establishment of a neuromuscular occlusal position is that it corresponded directly with the patient evaluation of significant improvement or cure of symptoms at each of the same stages of treatment. At 3 months under therapy, 88% of patients reported improvement or cure, and of those undergoing long-term treatment, 100% acknowledged significant improvement or cure.

In a carefully controlled and quantitative longitudinal study of 31 patients with signs and symptoms of functional disorders, Sheikholeslam et al., investigated clinically and electromyographically the long-term effects of occlusal splint therapy over a 7 year period.

The extensive statistical tests of quantitative EMG data indicated that postural activity of the patients decreased significantly in the masseter and temporalis muscles as signs and symptoms improved, following the splint therapy. Additionally, the treatment coincided with a more symmetric pattern of postural activity.

The 27 patients whose signs and symptoms had improved were asked to stop using the splint 3-6 months after treatment. 78% of these patients had recurring signs and symptoms during the 7 years of follow-up. The recurring signs and symptoms accompanied significant increases of EMG postural activity in the masseteric and temporal muscles.

Sheikholeslam, A., Holmgren, K., and Riise, C. A clinical and electromyographic study of the long-term effects of an occlusal splint on the temporal and masseter muscles in patients with functional disorders and nocturnal bruxism. *Journal of Oral Rehabilitation*, 13: 137-145, 1986.

SUMMARY

The postural activity of the temporal and masseter muscles in thirty-one patients with signs and symptoms of functional disorders were studied: before during and after 3-6 months of occlusal splint therapy. The fluctuating signs and symptoms, as well as the postural activity of the temporal and masseter muscles were significantly reduced after treatment. Further, the coefficients of correlation within pairs of postural activity of the right and left muscles increased significantly. After cessation of the splint therapy the signs and symptoms recurred to the pre-treatment level within 1-4 weeks in about 80% of the patients. The results indicate that an occlusal splint can eliminate or diminish signs and symptoms of functional disorders and re-establish symmetric and reduced postural activity in the temporal and masseter muscles, which can facilitate procedures, such as functional analysis and occlusal adjustment.

INTRODUCTION

The occlusal splint is one of the most generally accepted devices for treatment of signs and symptoms of functional disorders in the stomatognathic system. Its effectiveness has been questioned by Greene & Laskin (1972) who reported that there was a large placebo component in the subjective response of patients undergoing such therapy. Nevertheless, there is evidence that the use of the occlusal splint leads to improvement of dysfunctional signs and symptoms (Posselt & Wolff, 1963; Fuchs et al., 1972; Fuchs, 1975; Kovalevksi & De Boever, 1975; Clark et al., 1979; Zarb & Speck, 1979; Beard & Clayton, 1980; Wedel et al., 1981; Dahlstrm, Carlsson & Carlsson, 1982; Hamada et al., 1982).

In short-term investigations Jarabak (1956) reported that in patients with spasm in the temporal muscle, the postural activity decreased immediately after insertion of an occlusal splint. As the activity returned to the pre-treatment level 5 mm after the removal of the splint Jarabak (1956) concluded that the occlusion plays at least some part in the aetiology of temporal muscle spasm. Roura & Clayton (1975) found that 1 month of occlusal splint therapy in patients with TMJ dysfunction, there was relief of most of the clinical symptoms and reduction of postural activity in the elevator muscles.

In a previous report (Holmgren, Sheikholeslam & Riise, 1985), the immediate effects of occlusal splint therapy were described. Little is known, however, about the therapeutic mechanisms underlying the long-term effects of an occlusal splint. The purpose of the present study, the second one in a series performed during a period lasting up to 7 years, was to investigate both clinically and electromyographically the long-term effects of occlusal splint therapy in patients with functional disorders and nocturnal bruxism.

MATERIALS AND METHODS

Thirty-one patients (26 female, 5 male, 18-27 years, median 27) with signs and symptoms of functional disorders and nocturnal bruxism.

ELECTROMYOGRAPHY

The postural activity in the anterior temporal and masseter muscles was recorded bilaterally, with the patient seated upright without head support and looking straight forward and teeth apart. The activity was picked up by bipolar surface electrodes.

TREATMENT

The patients were examined in almost 2 week intervals, and the splint adjusted if necessary during the treatment period (3-6 months).

RESULTS

ELECTROMYOGRAPHY

On the average, the occlusal splint therapy resulted in a significant reduction of the postural activity during mandible at rest. Pairing the data of the postural activity in the right and left temporal muscles of twenty-seven patients whose signs and symptoms improved after splint therapy showed that the coefficients of correlation (r) within pairs of postural activity in the right and left temporal muscles increased from $r = + 0.48$ before, to $r = + 0.77$ after treatment ($z_0 = 1.86$, $0.05 < P < 0.10$).

Further, the postural activity was significantly reduced ($P < 0.05$) in the masseter muscle. In addition the coefficients of correlation (r) within pairs of postural activity in the right and left masseter muscles of twenty-seven patients whose signs and symptoms improved after splint therapy increased from $r = + 0.353$ before, to $r = + 0.686$ after treatment ($z_0 = 1.768$, $0.05 < P < 0.10$).

In a recent electromyographic study, Sheikholeslam, Moller & Lous (1982) reported that after conventional treatment of patients with functional disorders (occlusal splints, occlusal adjustments, etc.) the postural activity in the elevator muscles was reduced simultaneously with the improvement of signs and symptoms. Further, in a short-term study, Riise & Sheikholeslam (1982) reported that in less than 48 h after insertion of an artificial occlusal interference in the intercuspal position in subjects without a history of functional disorders, signs and symptoms of these disorders developed concomitantly with an increase of postural activity and improvement of the signs and symptoms. Thus, the occlusion is likely to be a co-factor in the development of muscular hyperactivity.

When the patients in this study were instructed to stop wearing the splint, the signs and symptoms of nocturnal bruxism returned to the pre-treatment level within a period of 1-4 weeks in 80 % of the patients. This is in line with Beard & Clayton (1980), Solberg et al., (1979), reporting that when the splint was removed in patients with habitual nocturnal bruxism, the cumulative EMG of the masseter muscles during sleep immediately increased to the pre-treatment level. Thus the splint therapy in most cases must be regarded as a symptomatic treatment.

Rugh & Solberg (1975) stated that nocturnal bruxism is closely related to the psychic stress level of the previous day. However, in the present study there were no attempts to treat or change the patients psychic state. Therefore the results suggest that the reduction of postural activity and improvement of signs and symptoms in at least 80% of the patients during the splint therapy, were not due to changes in the patient's daily psychological condition as stated in the questionnaires. Moreover, had it been so, one would expect that there should be no recurrence of signs and symptoms when the patients stopped wearing the occlusal splint.

The increase in the coefficients of correlation (r) within pairs of postural activity in the right and left temporal and masseter muscles after treatment was due to a more symmetric pattern of postural activity. This is consistent with the findings of Ramfjord (1961a) who reported that a well-balanced muscle activity during the rest position was recorded after successful treatment of patients with habitual bruxism. Recently, Sheikholeslam et al., (1982) reported that symmetry of the relative loading of the right and left anterior temporal muscle (assessed in term of coefficients of correlation by correlating postural activity as a percentage of maximal activity) increased after treatment. Moreover, as the mandible at rest in the upright position is controlled by muscular activity (Lund, Nishiyania & Moller, 1970; Moller, Sheikholeslam, & Lous, 1971; Moller, 1971; Rugh & Drago, 1981), the reduced and more symmetric postural activity in both temporal and masseter muscles after occlusal splint therapy in the present study may even be able to influence the position of the mandible. Kovalevski & De Bover (1975) found that in nine out of eleven patients with signs and symptoms of functional disorders, the position of the mandible in relation to the maxilla changed toward the side of the painful joint after one month of occlusal splint therapy. Further, Mejias & Mehta (1982) reported that there was a definite shift in the maxillomandibular relationship in favour of a more distal position of the mandible after splint therapy which is also in agreement with the findings of Riise & Sheikholeslam (1985) on patients after occlusal adjustment therapy.

The occlusal splint may be very valuable in the examination and treatment of patients with mandibular dysfunction. It is a simple device which can reduce signs and symptoms and establish a more symmetric muscular rest activity. The splint also enhances procedures such as functional analysis and occlusal adjustment, and is a valuable tool which can be used for periods of several years, especially in patients where other forms of treatment are difficult to perform.

CONCLUSION

As the splint can eliminate signs and symptoms of functional disorders and create symmetric and reduced postural activity in the temporal and masseter muscles, it may enhance procedure where functional analysis and occlusal adjustment are involved.

SECONDARY REFERENCES

[Surface Electromyography Studies cited within the articles reviewed in this publication]

- Abe, K., Takata, M., & Kawamura, Y. (1973) A study on inhibition on masseteric - motor fibre discharges by mechanical stimulation on the temporomandibular joint in the cat. *Archives of Oral Biology*, 18, 301.
- Adrian, E.D. and Bronk, D.W. (1929) *J. Physiol.* 67,119.
- Ahlgren, J. (1966) Mechanism of mastication. *Acta Odontol. Scand.*, 44, 1-109.
- Ahlgren, J. (1967) Kinesiology of the mandible, an EMG study. *Acta Odontol. Scand.* 25, 593-611.
- Ahlgren, J., Ingervall, B., and Thilander, B. (1973) Muscle activity in normal and postnormal occlusion. *Am. J. Orthod.*, 64, 445-456.
- Ahlgren, J., and Owall, B. (1970) Muscular activity and chewing force, a polygraphic study of human mandibular movements. *Arch. oral Biol.* 15, 271-280.
- Anderson, D.J., and Picton, D.C.A. (1958) Masticatory stresses in normal and modified occlusion. *Journal of Dental Research*, 37, 312.
- Arnold, K. (1972) Die Erfassung funktioneller Vernderungen in orofazialen System nach operativen Eingriffen (p. 83). *Med. Diss. Halle/S.*
- Bakke, M., and Moller, E. (1980) Distortion of maximal elevator activity by unilateral premature tooth contact. *Scand. J. Dent. Res.* 88, 67-75.
- Bakke, M., Moller, E., and Thorsen, N.M. (1980) Occlusal contact and maximal muscle activity in natural mandibular positions. *J. Dent. Res.* 59, Spec. Issue B, Abstr. 892.
- Beard, C.C., and Clayton, J.A. (1980) Effects of occlusal splint therapy on TMJ dysfunction. *Journal of Prosthetic Dentistry*.
- Berry, D.C. (1967) Facial pain related to muscle dysfunction. *Brit J. Oral Surg.* 4,222.
- Bigland, B. and Lippold, O.C.J. (1954a) The relation between force, velocity and integrated electrical activity in human muscles. *J. Physiol. (Lond.)* 123, 214-224.
- Bigland, B., and Lippold, O.C.J. (1954b) Motor unit activity in the voluntary contraction of human muscle. *J. Physiol. (Lond.)* 125, 322-335.
- Black, G.V. (1895) An investigation of the physical characters of human teeth in relation to their diseases, and to practical dental operations, together with the physical characters of filling materials. *Dental Cosmos*, 37, 469.
- Blume, D.G. A roentgenographic study of the position of the mandible in malocclusion of the teeth, class II, division I, (Angle) Thesis submitted as part of the requirement for the Degree of Master of Science of Dentistry, Northwestern University Dental School, 1947.
- Boering, G. (1966) Arthrosis deformans van het kaakgewricht. Thesis, Rijksuniversiteit te Groningen.
- Borelli, G.A. (1680) *De motu animalium*. *Trans. Royal Society Medicine* (1933), 26, 71.
- Bowman, V.R. A roentgenographic study of the movement of the mandible from rest position to occlusion of the teeth, Northwestern University Dental School, July 1948.
- Brown, G.L., and Burns, B.D. (1949) Fatigue and neuromuscular block in mammalian skeletal muscle. *Proc. Roy. Soc. B*, 136, 182-195.
- Bruno, S. (1971) Neuromuscular disturbances causing temporomandibular dysfunction and pain. *J. Prosthet Dent*, 26, 287-396.
- Buchanan, F. The electrical response of muscle in voluntary, reflex and artificial stimulation. *Wuart. J. Exper. Physiology*, 1: 211-242 (1908),

- Buchthal, F. (1966) Spontaneous and voluntary electrical activity in neuromuscular disorders. *Bull. N.Y. Acad. Med. Second Series*, 42, 521.
- Buchthal, F., Guld, C., and Rosenfaick, P. (1957) Volume conduction of the spike of the motor unit potential investigated with a new type of multielectrode. *Acts Physiol. Scand.* 38, 331.
- Buxbaum, J.D. (1982) Myofacial pain dysfunction syndrome. In: *Diagnosis and Treatment of Chronic Pain*. N.H. Hendler, D.M. Long and T.N. Wise (Eds). John Wright PSG mc: Boston, 161-182.
- Carlsson, G.E. (1974) Bite force and chewing efficiency. *Front. Oral Physiol.* 1, 265- 292.
- Chaco, J. (1973) Electromyography of the masseter muscles in Costen's syndrome. *J. Oral Med.* 28, 45.
- Clark, G.T., Beemsterboer, P.L., Solberg, W.K., & Rugh, J.D. (1979) Nocturnal electromyographic evaluation of myofascial pain dysfunction in patients undergoing occlusal splint therapy. *Journal of the American Dental Association*, 99, 607.
- Close, J.R. (1964) *Motor Function in the Lower Extremity*. Springfield, Ill., Thomas.
- Cnockaert, J.C., Lensel, G., and Pertuzon, E. (1975) Relative contribution of individual muscles to the isometric contraction of a muscular group. *J. Biomechanics* 8, 191-197.
- Copland, J. (1954) Abnormal muscle tension and the mandibular joint. *Dent. Rec.* 74, 331.
- Costen, J.B. (1934) Syndrome of ear and sinus symptoms dependent upon disturbed function of the temporomandibular joint. *Ann. Otol. Rhin. & Laryng.* 43, 1.
- Czeche, F. (1968) Die Bedeutung sensibler Afferenzen fr die willkrliche Einstellung des Kaudrucks. *Med. Diss. Halle/S.*
- Dahlstrom, L., Carlsson, G.E. & Carissom, S.G. (1982) Comparison of effects of electromyographic biofeedback and occlusal splint therapy on mandibular dysfunction. *Scandinavian Journal of Dental research*, 90, 151.
- de Boever, J. (1969) Experimental occlusal balancing-contact interference and muscle activity. *Parodontology*, 23, 59.
- de Boever, J. (1975) Radiotelemetrische en elektromyografische studie van de functionele occlusale krachten. Thesis, Gent.
- De Luca, C.J. and Forrest, W J. (1973) Force analysis of individual muscles acting simultaneously on the shoulder joint during isometric abduction. *J. J. biomechanics* 6, 385-393.
- Dellow, P G. and Lund, J.P. (1971) Evidence of central timing of rhythmical mastication. *Journal of Physiology, London*, 215, 1.
- Direnfeld, V.N. (1967) Muscle endurance in patients with temporomandibular dysfunction. Thesis, University of Illinois. As quoted in Laskin, D. M. (1969) Etiology of the pain-dysfunction syndrome. *J. Amer. Dent. Assoc.* 79, 147-153.
- Dubner, R., Sessle, B.J. and Storey, A.T. (1978) *The neural basis of oral and facial function*. Plenum Press, New York.
- Duchene, G.B.A.: *Physiologie des Mouvements*, J. B. Bailliere et Fills, Paris 1867.
- Eason, R.G. (1960) Electromyographic study of local and generalized muscular impairment. *J. Appl. Physiol.* 15, 479-482.
- Eccles, J.C. and Sherrington, C.S. (1930). *Proc. Roy. Soc. B*, 106,326.
- Eichner, K. (1963) Messung der Krfte bei Kauvorgngen. *Deutsche Zahnrtliche Zeitschrift*, 18, 915.
- Eriksson, P.O. (1982) Muscle-fibre composition of the human mandibular locomotor system. Enzyme - histochemical and morphological characteristics of functionally different parts. *Swedish Dental Journal.* 6, Suppl. 12.
- Fex, J. and Krakau, C.E.T. (1958) Frequency analysis of the piper rhythm. *Acts Psychiat. Neurol.*, 33, 54-68.

- Franks, A.S.T. (1957) Electromyography relative to the stomathognathic system: A review. *D. Practitioner & D. Record*, 8: 32-37.
- Franks, A.S. (1965) Masticatory muscle hyperactivity and temporomandibular joint dysfunction. *J. prosth. Dent.* 15,1122.
- Fuchs, P. (1975) The muscular activity of the chewing apparatus during night sleep. *Journal of Oral Rehabilitation*, 2, 35.
- Fuchs, P., Boos, W. & Laub, M. (1972) Experimentelle Untersuchungen zur Behandlung von funktionellen Kiefergelenksbeschwerden mit Aufbissplatten. *Deutsche Zahnärztliche Zeitung*.
- Gilson, A.S. & Mills, W.B. (1941). *Amer. J. Physiol.* 133,685.
- Goldstein, I. (1965) The relationship of muscle tension and autonomic activity to psychiatric disorders. *Psychosom. Med.* 27,39.
- Goldstein, I., Grinker, R.R., Heath, H.A., Olken, D., and Shipman, W.G. (1964) Study in psychophysiology of muscle tension: I, Response specificity. *Arch. Gen. Psychiat.* 11,322.
- Goubel, F. (1971) Relation entre l'E.M.G. integre et le travail mecanique dans le cas de mouvements, effectues a inertie constante avec ou sans charge. *J. Physiol. (Paris)* 63, 224.
- Greene, L.S. & Laskin, D.M. (1972) Splint therapy for the myofascial pain dysfunction (MPD) syndrome: a comparative study. *Journal of the American Dental Association*, 84, 624.
- Griffin, C.J. and Munro, R.R. (1971) Electromyography of the masseter and anterior temporalis muscles in patients with temporomandibular dysfunction. *Arch. oral Biol.* 16,929
- Grosfeld, O. (1965) Changes of muscle activity patterns as a result of orthodontic treatment. *Tr. Eur. Orthod. Soc.*, 41, 203-214.
- Grossman, W.J., Greenfield, B.E., and Timms, D.J. Electromyography as an aid in diagnosis and treatment analysis. *Am. J. Orthodont.*, 47: 481-497 (July) 1961.
- Guha, K. and Anand, S. (1978) Simulation linking EMG power spectra and rate coding. *Comput. Biol. Med.* 9, 213-221.
- Gwynne-Evans, E. (1954) The orofacial muscles, their function and behavior in relation to the teeth. *Trans. Eur. Orthod. Soc.*, p. 20.
- Hamada, T., Kotani, H., Kawazoe, Y., and Yamada, S. (1982) Effect of occlusal splints on the EMG activity of the masseter and temporal muscles in bruxism with clinical symptoms. *Journal of Oral Rehabilitation*, 9, 919.
- Hannam, A.G, De Cou, R.E, Scott, J.D., & Wood, W.W. (1977) The relationship between dental occlusion, muscle activity and associated jaw movement in man. *Archives of Oral Biology*, 22, 25.
- Hannam, A.G., and Lund, J.P. (1981) The effect of intra-oral stimulation on the human masticatory cycle. *Archives of Oral Biology*, 26, 865.
- Hannam, A.G., Scott, J.D., and DeCou, R.E. A computer-based system for the simultaneous measurement of muscle activity and jaw movement during mastication in man. *Arch Oral Biol* 22:17, 1977.
- Hashimoto, T. (1969) An electromyographic study on the effects of prosthetic treatment in the molar region. *J. Osaka Odont. Soc.*, 32, 58-92.
- Hayes, K.J. (1960) Wave analysis of tissue noise and muscle action potentials. *J. Appi. Physiol.*, 15, 749-752.
- Helkimo, E., Carlsson, G.E., and Carmeli, Y. (1975) Bite force in patients with functional disturbances of the masticatory system. *J. Oral Rehabil.* 2, 397-406.
- Hofer, P.F.A. Electromyographic study of motor system in man. *Monatschr. f. Psychiat. u. Neurol.* 117:241, 1949.
- Hof, A.L., and Van Den Berg, J.W. (1981) EMG to force processing, 4 parts. *J. Biomechanics.* 14, 747-792.

- Hof, A. L., and Van Den Berg, J.W. (1977) Linearity between the weighted sum of the EMGs of the human triceps surae and the total torque. *J. J. biomechanics* 10, 159-166.
- Homma, S. Ishikawa, K., and Stuart, D.G. (1970) Motoneuron responses to linearly rising muscle stretch. *Amer. J. of Phys. Med.*, 40, 290-306.
- Humphreys, P.W., and Lind, A.R. (1963) The blood flow through active and inactive muscles of the forearm during sustained hand-grip contractions. *J. Physiol., London.* 166, 120-135.
- Ingervall, B., and Carlsson, G. E. (1982) Masticatory muscle activity before and after the elimination of balancing side occlusal interference. *Journal of Oral Rehabilitation*, 9, 183.
- Ingervall, B., and Thilander, B. (1975) Activity of temporal and masseter muscles in children with a lateral forced bite. *The Angle Orthodontist* 45, 249.
- Inman, V.T., Ralston, H.J., and Sanders, M. et al., (1952) Relation of human electromyogram to muscular tension. *EEG Clin. Neurophysiol.*, 4, 187-194.
- Jarabak, J.R. (1956) An electromyographic analysis of muscular and temporomandibular joint disturbances due to imbalances in occlusion. *The Angle Orthodontist*, 26,170.
- Jarabak, J.R. The Adaptability of the Temporal and Masseter Muscles: An Electromyographical Study. *Angle Ortho.*, Vol. XXIV, No. 4, 1954.
- Johansson, R.S., and Olsson, K. (1976) Microelectrode recordings from human oral mechanoreceptors. *Brain Research*, 118, 307.
- Komi, P.V. et al. (1977) Skeletal muscle fibres and muscle enzyme activities in monozygous and dizygous twins of both sexes. *Acta Physiol. Scand.* 99, 105-109.
- Kopp, S. (1977) constancy of clinical signs in patients with mandibular dysfunction. *Community Dent. Oral Epidemiol.* 5, 94-98.
- Kovalevksi, W.C., and De Boever, J. (1975) Influence of occlusal splints on jaw position and musculature in patients with temporomandibular joint dysfunction. *Journal of Prosthetic Dentistry*, 33, 321.
- Kramer, H. (1979) Changes in mechanical and bioelectrical muscular activity and in heart rate due to sustained voluntary isometric contractions. *Electromyogr. Clin. Neurophysiol.* 19, 381-386.
- Kydd, W.L. (1959) Psychosomatic aspects of temporomandibular joint dysfunction. *J. Amer. dent. Assoc.* 59, 31.
- Laskin, D. (1969) Etiology of the pain-dysfunction syndrome. *J. Am. Dent. Assoc.*, 79, 131-136.
- Lewis, Sir Thomas: Pain, The Macmillan Company, New York.
- Liebman, F.M., & Cosenza, F. (1960) An evaluation of electromyographic in the study of the etiology of malocclusions. *J Prosthet Dent*, 10, 1065-1077
- Linderhoim, H., and Wennstrom, A. (1970) Isometric bite force and its relation to general muscle force and body build. *Acta Odont. Scand.* 28, 679-689.
- Lindstrom, L. (1974) A model describing the power spectrum of myoelectric signals, research laboratory of medical electronics. Chalmers University of Technology, Goteborg, Sweden, 4 parts.
- Lippold, O.C.J. (1952) The relationship between integrated action potentials in a human muscle and its isometric tension. *J. Physiol. (Lond.)* 177, 492-499.
- Lous, I., Sheikholeslam, A., and Moller, E. (1970) Postural activity in subjects with functional disorders of the chewing apparatus. *Scand. J. Dent. Res.* 78, 404-410. *See Abstract on page 43.*
- Lund, J.P. (1976) Evidence for a centralneural pattern generator regulating the chewing cycle. In: Mastication (eds D. J. AndeEson & B. Mathews), p. 204. Wright, Bristol.
- Lund, J.P., and Larnarre, Y. (1973) The importance of positive feedback from periodontal pressoreceptors during voluntary isometric contraction of jaw closing muscles in man. *Journal de Biologie Buccale Paris*, 1, 346.

- Malmö, R.B., and Shagass, C. (1949) Physiologic studies of reaction to stress and anxiety and early schizophrenia. *Psychosom. Med.* 11, 9.
- Mansour, R.M., and Rejzlik, R.J. (1975a) In vivo occlusal forces and moments - I. Forces measured in terminal hinge position and associated moments. *J. Dent. Res.* 54, 114-120.
- Mansour, R.M., and Rejzlik, R.J. (1975b) In vivo occlusal forces and moments - II. Mathematical analysis and recommendations for instrumentation specifications. *J. Dent. Res.* 54, 121-124.
- Marbach, J.J., and Lipton, J.A. (1977) The relationship of diagnosis treatment in the facial pain patient. *NY State Dent. J.*, 43, 282-285.
- Marklund, G., and Molin, C. (1972) Horizontal isometric muscle forces of the mandible. *Acta Odont. Scand.* 30, 97-115.
- Maton, B., and Bouisset, S. (1977) The distribution of activity among the muscles of a single group during isometric contraction. *Europ. J. Appl. Physiol.* 37, 101-109.
- Mikhael, M., & Rosen, H. (1980) History and etiology of myofascial pain-dysfunction syndrome. *J. Prosthetic Dent.*, 44, 438-444.
- Milner-Brown, H.S., and Stein, R.B. (1975) The relation between the surface electromyogram and muscular force. *J. Physiology (London)*. 246, 549-569.
- Molin, C. (1972) Vertical isometric forces of the mandible. *Acta Odont. Scand.* 30, 485-499.
- Molin, C. (1973a) Etiology of mandibular pain dysfunction syndrome: A survey of a female patient group. To be published.
- Møller, E. (1966) The chewing apparatus: An electromyographic study of the action of the muscles of mastication and its correlation to facial morphology. *Acta Physiol. Scand.* 69, Suppl. 280.
- Møller, E. (1970) Computer analysis of electromyographic data in clinical studies of oral function. *Scandinavian Journal of Dental Research*, 78, 411-416.
- Møller, E. (1974) Action of the muscles of mastication, in Kawamura, Y. (ed): *Frontiers of Oral Physiology*. Basel, Karger, pp. 121-158.
- Møller, E., and Troelstrup, B. (1975) functional and morphological asymmetry in children with unilateral cross-bite. *J. of Dental Res.* 54, Special Issue A, L45 (Abstract).
- Møller, E., Lous, I., and Sheikholeslam, A. (1977) Activity symptoms and signs of elevators: response to occlusal adjustment. *J. Dent. Res.* 56, Spec. Issue A, L 508.
- Møller, E., Sheikholeslam, A. and Lous, I. (1971) Deliberate relaxation of the temporal and masseter muscles in subjects with functional disorders of the chewing apparatus. *Scand. J. Dent. Res.* 79, 478.
- Møller, E., Sheikholeslam, A. & Lous, I. (1984) Response of masticatory activity in mandibular elevators to treatment of functional disorders. *Scandinavian Journal of Dental Research*, 92, 64.
- Moss, J.P., & Chalmers, C.P. (1974) An electromyographic investigation of patients with normal jaw relationship and a Class III jaw relationship. *Am. J. Orthod.* 66, 538-556
- Moss, J.P., & Greenfield, B.E. (1965) An electromyographic investigation and survey of Class II cases. *Tr. Br. Soc. Study Orthod.*, pp. 147-156.
- Moyers, R.E. (1949) Temporomandibular muscle contraction patterns in Angle Class II Division I malocclusions: an electromyographic analysis. *Am. J. Orthodont.*, 35, 837-857.
- Moyers, R.E. (1950) An electromyographic analysis of certain muscles involved in temporomandibular movement. *Am. J. Orthodont.*, 36: 481-515.
- Muguruma, T. (1965) Studies on a prosthodontic analysis of electromyograms of masticatory muscles. *J. Osaka Odont. Soc.*, 28, 615-650.

- Munro, R.R. (1975) Electromyography of the masseter and the anterior temporalis muscles in open-close-clench cycle in temporomandibular joint dysfunction. *Managr Oral Sd*, 4, 117-125.
- Nakamura, Y., Kubo, Y., Nozaki, S., and Takatori, M. (1976) Cortically induced masticatory rhythm and its modification by tonic peripheral inputs in immobilized cats. *Bulletin Tokyo Medical and Dental University*, 23, 101.
- Naeije, M., and Zorn, H. (1981) Changes in the power spectrum of the surface electromyogram of the human masseter muscle due to local muscular fatigue. *Arch. Oral Biology*, 26, 409.
- Ness, A.R. (1954) The mechanoreceptors of the rabbit mandibular central incisor. *J. of Physiol.* 126, 475.
- Newton, A.V. (1969) Predisposing causes for temporomandibular joint dysfunction. *J. Prosth. Dent.* 22,67.
- Olson, C.B., Carpenter D.O., and Henneman, E. (1968) Orderly recruitment of muscle action potentials. *Arch. Neurol.* 19, 591-597.
- Pancherz, H. (1980) Activity of the temporal and masseter muscles in Class II, Division I malocclusions. *Am. J. Orthod.*, 77, 679-688.
- Perry, H.T. (1957) Muscular changes associated with temporomandibular joint dysfunction. *J. Amer. Dent. Ass.* 54,644.
- Perry, H.T. (1955) Functional Electromyography of the Temporal and Masseter Muscles in Class II, Division I Malocclusion and Excellent Occlusion. *Angle Ortho.*
- Perry, H.T., Jr. (1955) Implications of myographic research. *Angle Orthodont.*, 25, 179-188.
- Perry, H.T. (1954) An electromyographic study of the temporal and masseter muscles of Class II Division I malocclusion patients and normal occlusion patients during function. Master's thesis, Northwestern University.
- Petrofsky, J.S. (1979) Computer analysis of the surface EMG during isometric exercise. *Comput. Biol. Med.* 10, 83-95.
- Pfaffman, C. (1939) Afferent impulses from the teeth due to pressure and noxious stimulation. *J. of Physiol.* 97, 207.
- Piper, H. (1912) *Electrophysiologic menschlicher Muckeln*, Berlin.
- Porritt, J.E. An electromyographic study involving occlusal interferences. *Am. J. Orthodont.*, 46: 57-58 (Jan.) 1960.
- Pruzansky, S. (1952) Application of Electromyography to Dental Research, *J. Am. Dent. Assoc.* 44: 49-68.
- Ralston, H.J. (1961) Uses and limitations of electromyography in the quantitative study of skeletal muscle function. *Am. J. Orthodont.* 47, 521-530.
- Ramfjord, S.P. (1961) Bruxism, a clinical and electromyographical study. *Journal of American Dental Association*, 62, 21.
- Ramfjord, S.P. (1961) Dysfunctional temporomandibular joint and muscle pain. *J. Prosthet. Dent.* 11, 353-374.
- Randow, K., Carlsson, K. Edlund, J., and Oberg, T. (1976) the effect of an occlusal interference on the masticatory system. *Odontologisk Revy*, 27, 245.
- Rau, S., and Vredembregt, J. (1973) EMG-force relationship during voluntary static contractions (M. Biceps). In: *Medecine and Sport*, Karger, Basel, Vol. 8 Biomechanics III: 270-274.
- Reid, C. (1928) The mechanism of voluntary muscular fatigue. *Quart. J. Exptl. Physiol.* 19, 17-42.
- Ricketts, R.M. (1950) Variations of the Temporomandibular Joint as Revealed by Cephalometric Laminagraphy, *Am. J. Ortho.* 36, 877-898.
- Riise, C., and Sheikholeslam, A. (1982) The influence of experimental interfering occlusal contacts on the postural activity of the anterior temporal and masseter muscles in young adults. *J. Oral Rehabilitation*, 9, 419.
- Riise, C., and Sheikholeslam, A. (1983) The influence of experimental interfering occlusal contacts on the activity of the anterior temporal and masseter muscles during submaximal and maximal bite in the intercuspal position. *J. Oral Rehabilitation*, 10, 207.

- Riise, C., and Sheikholeslam, A. (1983a) The influence of experimental interfering occlusal contacts on the activity of the anterior temporal and masseter muscles during mastication. *J. Oral Rehabilitation*, (accepted for publication, 1983).
- Ringquist, M. (1973) Fibre size of human masseter muscle in relation to bite force. *J. Neurol. Sci.* 19, 297-305.
- Rix, R.E. (1946) Deglutition and teeth. *Dent. Rec.* 66, 103.
- Rushworth, G. (1961) Spasm of skeletal muscle: some aspects from the standpoint of clinical neurophysiology. In: *Skeletal muscle spasm*, Riker Symposium, (no editor cited) Ward and Wheeler, Leicester pp. 9-29.
- Saltin, B. et al., (1976) The nature of training response; peripheral and central adaptations to one-legged exercise. *Acta Physiol. Scand.* 96, 289-305,
- Samejima, M. (1971) Frequency analytical data processing of surface electromyogram and its clinical application. 21, 292-319.
- Sato, K., and Tsuruma, S. (1967) A scope of the frequency analysis of the electromyogram. *Annual report of Physical Education*, 1, 7-28,
- Schaerer, P., Stallard, R. E., and Zander, H.A. (1967) Occlusal interferences and mastication: An electromyographic study. *Journal of Prosthetic Dentistry*, 17, 438.
- Schpuntoff, H., and Schpuntoff, W. (1956) A study of physiologic rest position and centric position by electromyography. *J. Pros. Den.*, 6: 621-628.
- Schroeder, J. (1927) *ber Kaudruck*. In: *Lehrbuch der Technischen Zahnheilkunde*. Neuszer Verlag, Berlin.
- Sheikholeslam, A., and Riise, C. (1983) Influence of experimental interfering occlusal contacts on the activity of the anterior temporal and masseter muscles during submaximal and maximal bite in the intercuspal position. *J. Oral Rehabilitation*, 10, 207-214.
- Sheikholeslam, A., Moller, E., and Lous, I. (1980) Pain, tenderness and strength of human mandibular elevators. *Scand. J. Dent. Res.* 88, 60-66.
- Sheikholeslam, A., Moller, E. and Lous, I. (1982) Postural and maximal activity in elevators of mandible before and after treatment of functional disorders. *Scand. J. Dent. Res.* 90, 37-46.
- Shipman, W.G., Oken, D., Goldstein, I.B., Grinker, R.R., and Heath, H.A. (1964) Study in psychophysiology of muscle tension: II, Personality factors. *Arch. Gen. Psychiat.* 11,330.
- Steenberghe, D., and de Vries, J.H. (1978) The influence of local anaesthesia and occlusal surface are on the forces developed during repetitive maximal clenching efforts. *Journal of Periodontal Research*, 13, 270.
- Steenberghe, D., and de Vries, J.H. (1978) The development of maximal clenching force between two antagonistic teeth. *J. Periodontal Res.* 13, 91-97.
- Swanson, A.G. (1971) Prominent neurologic symptoms and their management: pain. In: Besson, P. B. and McDermott, W. (eds) *Cecil-Loeb Textbook of Medicine*, Vol. 1, 13th ed. Saunders, Philadelphia. pp. 149-154.
- Tawa, N. (1971) On the EMG coordination pattern of the jaw-closing muscles during mastication. *J. Jap. Pros. Soc.*, 15, 48-66.
- Tesch, P., & Karlsson, J. (1978) Isometric strength performance and muscle fibre type distribution in man. *Acta Physiol. Scand.* 103, 47-51.
- Thompson, J.R. Concepts regarding function of stomatognathic system. *J.A.D.A.* 48:626, June 1954.
- Thompson, J.R. Factors in the Position of the Mandible, *J. Am. Dent. Assoc.* 29: 925-941, 1942.
- Thorstensson, A. Grimby, G., and Karisson, J. (1976) Force velocity relation and fiber composition in human knee extensor muscles. *J. Appi. Physiol.* 40, 12-16.
- Thorstensson, A., Hulten, B., von Döbeln, W., and Karisson, J. (1976) Effect of strength training on enzyme activities and fibre characteristics in human skeletal muscle. *Acta Physiol. Scand.* 96, 392-398.

- Todd, M.E. *The Thinking Body*. New York, Harper & Bros., 1937.
- Travell, J. (1960) Temporomandibular joint pain referred from muscles of head and neck. *J. Prosth. Dent.* 10,745.
- Troelstrup, B., and Moller, E. (1970) Electromyography of the temporalis and masseter in children with unilateral cross-bite. *Scand. J. Dent. Res.* 78, 425-430.
- Tulley, W. J. (1953) Methods of recording patterns of behavior of the oro-facial muscles using the electromyograph. *Dent. Rec.* 73, 741.
- Vestergaard Christensen, L. (1967) Facial pain from the masticatory system induced by experimental bruxism. *Tandlaegebladet*, 71, 1171.
- Vestergaard Christensen, L. (1971) Facial pain and internal pressure of masseter muscle in experimental bruxism in man. *Arch. Oral Biol.* 16, 1021.
- Viitasalo, J.H.T. and Komi, P.V. (1975) Signal characteristics of EMG with special reference to reproducibility of measurements. *Acts Physiol. Scand.* 93, 531- 539.
- Vitti, M., & Basmajian, J.V. (1975) Muscles of mastication in small children: an electromyographic analysis. *Am J Orthod.*, 68, 412-419.
- Vitti, M., & Basmajian, J.V. (1977) Integrated actions of masticatory muscles: simultaneous EMG from eight intramuscular electrodes. *Anat. Rec.*, 187, 173-189
- Wedel, A., Carlsson, G. E., Dahlstrom, L. Kallenberg, A., Kopp, S., Lundqvist, S., Mejersj, C., and Wennebrg, B. (1981) Stabiliseringsskena eller avslappningsplt - en jmfrelse mellan tv typer av bettskenor. *Tandikartidningen*, 4, 137.
- Weinberg, L.A. (1974) Temporomandibular dysfunctional profile: a patient orientated approach. *J. Prosth. Dent.* 32,312.
- Wentz, F.M.: Personal Communication.
- Wilcot, R.C., and Beenken, H.G. (1957) Relation of integrated surface electromyography and muscle tension. *Percept. Motor Skills.* 7, 295-298.
- Wolf, S., Basmajian, J., Russe, T., and Kutner, M. (1979) Normative data on low back mobility and activity levels. *American Journal of Physical Medicine*, 58, 217-229.
- Wolff, H.G. (1972) *Headache and other head pain*. 3rd Ed., (revised by Dalessio, D.J.) Oxford University Press, New York. Cli. 19.
- Worner, H.K., and Anderson, M.N. (1944) Biting force measurements on children. *Australian Dental Journal*, 48, 1.
- Wyke, B.E.D. *Lecture*. R.C.S. England, 1959.
- Yemm, R. (1977) The representation of motor-unit action-potentials on skin- surface electromyograms of the masseter and temporal muscles in man. *Archs Oral Biol.* 22, 201-205.
- Yemm, R. (1969) Temporomandibular dysfunction and masseter muscle response to experimental stress. *Br Dent J.* 127, 508-510.
- Zarb, G.A., & Speck, J.E. (1979) The treatment of mandibular dysfunction. In: *Temporomandibular Joint* (eds G.A. Zarb & G.E. Carlsson), Munksgaard, p. 373.

LITERATURE REVIEW OF SCIENTIFIC STUDIES
SUPPORTING THE EFFICACY OF LOW FREQUENCY T.EN.S.
IN THE DIAGNOSIS AND TREATMENT OF TMD

INTRODUCTION

T.E.N.S. modalities are designated into three distinct categories based on technical parameters and physiologic action. (Mannheimer, J. *Clinical Transcutaneous Electrical Nerve Stimulation*. F.A. Davis, Philad., 1986).

A T.E.N.S. mode that uses high rate (50 to 100 Hz), asymmetrical biphasic wave (40-75 usec) is referred to as Conventional. High Frequency T.E.N.S. This mode is designed to selectively actuate the large myelinated afferent fibers. Muscle fasciculation is not apparent. Conventional high frequency T.E.N.S. is characterized by fast onset of relief, short therapeutic effect, generally not exceeding length of stimulation. There is little or no endogenous opiate liberation and no reversal by naloxone. The high frequency T.E.N.S. is primarily a local CNS (segmental effect).

A second T.E.N.S. mode is Low Frequency Acupuncture-like T.E.N.S. with a pulse rate of 0.5 Hz to 10.0 Hz using an asymmetrical biphasic wave form of 150-500 usec. It produces muscle contraction, slow onset (20 mm. or more), long therapeutic effect and activates small pain afferent and motor efferent fiber stimulation. There is endogenous opiate liberation, naloxone reversal and long therapeutic effect. The Low Frequency T.E.N.S. allow a period for muscle recovery between pulses with stimulation by surface electrodes in segmentally related myotomes being most efficacious. The Myo-monitor is a low frequency acupuncture-like T.E.N.S.

The third type of T.E.N.S. is an Electrogalvanic Stimulator (E.G.S.) It is characterized by having a monophasic, twin peak wave for each pulse of 10-20 msec utilizing direct current. E.G.S. is designed for local tissue effect, not pain control.

Both low and high frequency T.E.N.S. have ample and specific documentation in the medical literature regarding local histochemical and endorphin effects. The following articles address the mode of action of conventional high frequency T.E.N.S. and low frequency acupuncture-like T.E.N.S.

1. Ersek, R. (1977) Transcutaneous neurostimulation: A new therapeutic - modality for controlling pain. *Clinical Orthopedics and Related Research*. Vol. 128:314-324.
2. Eriksson, M.D., and Sjolund, B.H. (1978) Pain relief from conventional versus acupuncture-like T.E.N.S. in patients with chronic facial pain. *Pain Abstracts*. 2nd World Congress on Pain, Montreal: IASP, p 128.
3. Takakora, K., et al. (1979) Pain control by transcutaneous electrical nerve stimulation using irregular pulse of 1 Hz fluctuation. *Applied Neurophysiology*. 42:314.
4. Murray, W., and Miller, J. (1960) Potency differences of morphine-type agents by radiant heat and 'cramping' analgesic assays provide evidence for potentializing substance from the posterior pituitary gland. *J. *pharmacologic Exp. Ther.* pp 128-380.
5. Goldstein, A., Lowney, L., and Pal, B. (1971) Stereospecific and nonspecific interactions of the morphine narcotic congener leurophanol in subcellular functions of rat brain. *Proc. Nat. Acad. Science USA*. 68:1742.
6. Moyer, D.J., Price, D.D., and Rafii, A. (1977) Antagonism of acupuncture analgesia in man by the narcotic antagonist naloxone. *Brain Research*. pp 121-368.
7. Akil, H., et al. (1978) Enkephalin-like material elevated in ventricular cerebrospinal fluid of pain patients after Analgesic facial stimulation. *Science*. 201:463.
8. Simantor, R., et al. (1976) The regional distribution of a morphine-like enkephalin in monkey brain. *Brain Research*. 106:189.
9. Sjolund, B., and Eriksson, M. (1979) Endorphins and analgesia produced by peripheral conditioning stimulation. *Advances in Pain Research And Therapy*, vol. 3, Bonica, et al., eds. Raven Press, N.Y.
10. Wall, P.D. (1980) The role of substantia gelatinosa as a gate control. *Pain. Research Ed. Bonica*, 58:205.
11. Kerr, F.W. (1975) Neuroanatomical substrates of nociception in the spinal cord. *Pain*. 1:325.
12. Loeser, J.D., et al. (1975) "Relief of pain by transcutaneous stimulation." *J. Neurosurg*. 42:308.

13. Arcangeli, P., and Galletti, R. (1974) Endogenous pain producing substances. *Recent Advances on Pain: Pathophysiology and Clinical Aspects*. Ed. Bonica, p 36.
14. Thorsteinsson, G., et al. (1977) Transcutaneous electrical stimulation: A double-blind trial of its efficacy for pain. *Arch. Phys. Med. Rehab.* 58:8.
15. Long, D., and Hagfors, N. (1975) Electrical stimulation in the nervous system: The current status of electrical stimulation of the nervous system for relief of pain. *Pain.* 1:109.
16. Dooley, D.M., and Kasprak, M. (1976) Modification of blood flow to the extremities by electrical stimulation of the nervous system. *S. Med. Journal* 69: 1309.
17. Abram, S.E. (1976) Increased sympathetic tone associated with transcutaneous electrical stimulation. *Anesthesiology.* 45:575.
18. Abram, S.E., et al. (1980) Increased skin temperature during transcutaneous electrical stimulation. *Anesth. Anaig.* 59:22.
19. Rowlingson, J., et al. (1978) The effect of transcutaneous nerve stimulation on blood flow in normal extremities. *Pain Abstr. Vol. 1, 2nd World Congress on Pain, mt. Assoc. for Study of Pain, Seattle*, p 155.
20. Murphy, T.M., and Bonica, J.J. (1977) Acupuncture analgesia and anesthesia. *Arch. Surg.* 112:896.
21. Andersson, S.A., and Holmgren, E. (1977) Analgesic effects of peripheral conditioning stimulation parameters. *Acupunct. Electro. Res.* 2:237.
22. Sjolund, B.H., and Ericksson, M.E. (1976) Electro-acupuncture and endogenous morphines. *Lancet.* 2:1085.
23. Voll, R. (1975) Twenty years of electroacupuncture therapy using low- frequency current pulses. *American J. of Acupuncture.* 3:291.
24. Kosterlitz, H.W., and Hughes, J. (1976) Possible physiologic significance of enkephalin on endogenous ligand of opiate receptors. *Advances in Pain Research and Therapy*. Ed. Bonica, Raven Press, N.Y., p 641.
25. Terenius, L. (1978) Significance of endorphins in endogenous antinociception. *Advances in Biochemical Psychopharm.* Ed. Costa and Trabucchi. Raven Press, N.Y., p 31.
26. Adams, J.E. (1976) Naloxone reversal of analgesia produced by brain stimulation in the human. *Pain.* 2:161.
27. Hosobuchi, Y., et al. (1977) Pain relief by electrical stimulation of the central grey matter in humans and its reversal by naloxone. *Science.* 17:183.
28. Burton, C., and Marrer, D.D. (1974) Pain suppression by transcutaneous electrical stimulation. *IEEE Trans. Biomed. Eng.* 21:81.
29. Andersson, S.A., et al. (1976) Evaluation of the pain suppression effect of different frequencies of peripheral electrical stimulation in chronic pain conditions. *Acta Orthop. Scandia.* 47:149.
30. Wolf, C.J., et al. (1980) Antinociceptive effect of peripheral segmental electrical stimulation in the rat. *Pain.* 8:237.
31. Malow, R.M., and Dougher, M.J. (1979) A Signal detection analysis of the effects of transcutaneous stimulation on pain. *Psychosom. Med.* 4:101.
32. Ebersold, M.J., Laws, E.R., and Albers, L.W. (1977) Measurements of autonomic function before, during and after transcutaneous stimulation in patients with chronic pain and in control subjects. *Mayo Clin. Proc.* 52:228.
33. Pert, A., and Yaksh, T. (1974) Sites of morphine induced analgesia in the primate brain: Relation to pain pathways. *Brain Research.* 80:135.

34. Sjolund, B.H., Terenius, L., and Ericksson, M.B, (1977) Increased cerebrospinal fluid levels of endorphin after electro-acupuncture. *Acta Physiol. Scand.* 100:382.
35. Mayer, D.J., Price, D.D., and Raffii, A. (1977) Antagonism of acupuncture analgesia in man by the narcotic antagonist naloxone. *Brain Res.* 121:368.
36. Schien, H., and Bentley, G.A. (1980) The possibility that a component of morphine induced analgesia is contributed indirectly via the release of endogenous opioids. *Pain.* 9:73.
37. Mao, W., et al. (1980) High versus low intensity acupuncture analgesia for treatment of chronic pain: Effects on platelet serotonin. *Pain.* 8:331.
38. Cheng, R.S., and Pomeranz, B. (1981) Monoaminergic mechanism of electroacupuncture analgesia. *Brain Res.* 215:77.
39. Cheng, R.S., and Pomeranz, B. (1980) Electroacupuncture is mediated by stereospecific opiate receptors and is reversed by antagonists of type I receptors. *Life Science.* 26:631.
40. He, L. (1987) Involvement of endogenous opioid peptides in acupuncture analgesia. *Pain.* 31:99-121.
41. Chen, B.Y., and Pan, X.P. (1984) Correlation of pain threshold and level of beta-endorphin-like immunoreactive substance in human CFS during electroacupuncture analgesia. *Acta Physiol.* 36:183-187.
42. Chan, C.W., and Tsang, H. (1987) Inhibition of the human flexion reflex by low intensity, high frequency transcutaneous electrical nerve stimulation (TENS) has a gradual onset and offset. *Pain.* 28:239-253.
43. Facchinetti, F., et al. (1981) Concomitant increase in nociceptive flexion reflex threshold and plasma opioids following transcutaneous nerve stimulation. *Pain.* 11:49-63.
44. Hansoon, P., and Ekblom, A. (1983) Transcutaneous electrical nerve stimulation (TENS) as compared to placebo TENS for relief of acute oro-facial pain. *Pain.* 15:157-165.

The medical literature is clear and unequivocal - low frequency T.E.N.S. (0.5 - 10 Hz) is both safe and efficacious for muscle relaxation and pain control. It is also clear that low frequency T.E.N.S. has a high degree of specificity when utilized for craniofacial pain (Andersson, 1979; Eriksson et al., 1984; Chapman et al., 1979; Andersson et al., 1977; Andersson and Holmgren, 1975; Sjolund et al., 1975; Reichmanis and Becker, 1977; Hansoon and Ekblom, 1983; Tereshalmy et al., 1982; Phero, 1987; Lasagna et al., 1986; Thomas, 1986; Pantaleo et al., 1983; Wessberg and Dinhani, 1977; Konchak et al., 1988).

Choi and Mitani at Osaka Dental University in 1973 applied the Myomonitor to 15 subjects and monitored the evoked response using wire EMG electrodes. The study concluded "The evoked EMG was recorded from the anterior portion of the temporal, the masseter, the anterior ventral of the digastric, and obicularis oris and the buccinator muscles. . . The Myo-monitor pulse stimulates the nerve trunks of the fifth and seventh cranial nerves at the superior mandibular notch percutaneously and it appeared to have afferent and efferent effects."

Using accepted intensity-duration methodology Jankelson, et al., 1975 demonstrated that the chronaxy values for Myo-monitor generated curves were well below those for direct muscle stimulation. Further verification of neural mediation resulted from the study of Williamson and Marshall, 1986 using succinylcholine. The study concluded "Succinylcholine acts by competing with acetylcholine at the myoneural end plate and, therefore, no neurally stimulated muscle contraction under such conditions is by direct depolarization of the muscle itself. With the Myo-monitor evoking electrical impulses, there was no muscle contraction in either instance. This information would support the conclusion that the Myo-monitor stimulus is transmitted neurally."

Fujii 1977 at the University of Osaka used multiple site monitoring to distinguish M wave and H wave response. Using multiple anatomically separate recording sites the study concluded "Two kinds of response were obtained with latencies of about 2.0 msec. and about 6.0 msec. respectively. The former was assumed to be a direct potential (M wave) and the latter a monosynaptic reflex potential (H wave)." The use of recording sites anatomically distant from the input stimuli is essential for valid conclusions using this methodology. In a 1988 study of Myo-monitor stimulation, Dao, Feine and Lund for unexplained reasons placed the recording needle proximate to the electrode stimuli site.

McMillan et al., 1987 at the University of Hong Kong concluded that "Contraction of muscles of the upper and lower eyelids, the lateral aspect of the nose and the upper lip indicates stimulation of the facial nerve, in particular its zygomatic and buccal branches. The results of our anatomic investigation indicate that this effect is produced by the stimulation of the branches of the upper division of the facial nerve as they pass in a more or less direct anterior course over the preauricular region. These branches will then be directly beneath a surface electrode placed according to the standard protocol. Propagation of the Myo-monitor stimulus along branches from the buccal anastomotic loops of the nerve would ensure contraction of muscles of the upper lip and angles of the mouth. . . This observation supports electromyographic evidence and results of intensity duration tests that indicate muscle contraction resulting from Myomonitor stimulation is neurally mediated."

Goodgold and Eberstein examined eight individual investigative studies and found that normal distal latency and conduction velocity of peripheral motor nerves ranged from 2.1 to 5.6 msec. and 44.8 to 67.9 msec., respectively. They concluded that the latency to the obicularis oris which is innervated by the facial nerve in response to stimulation at the angle of the jaw, averages 2.5 to 3.0 msec. Basmajian summarized the results of six studies conducted by separate authors on peripheral nerve conduction velocity and found a range of conduction velocity between 37 and 73 meters/sec. Assuming the distance between the stimulation electrode and the wire recording electrode was approximately 2 cm, it should have taken 0.27 to 0.54 msec. for the pulse to travel this distance if the muscles were stimulated directly. This time interval is much less than the 1.80 to 4.4 msec. measured in the Dao study. This suggests the pulse must have traveled a much longer distance. A neurally mediated pulse would have: 1) 0.5 msec. charging the dermal capacitance, 2) neural conduction time of 0.7 msec. assuming a neural conduction pathway of 4 cm and conduction velocity of 55 meters/sec. which is the average of Basmajian's review, 3) residual latency (delay at the myoneural junction) of 0.6 msec., 4) intermuscular delay of approximately 0.4 msec. depending upon electrode placement. Adding the sum of these phenomena we find the latency of 1.80 to 4.04 msec. as measured by Dao, et al. is well within the range of neurally mediated response, despite their electrode placement.

ARTICLES REVIEWED IN THIS PUBLICATION

SECTION 1: STUDIES THAT DOCUMENT EFFICACY OF LOW FREQUENCY TENS

1. Andersson, S. Pain control by sensory stimulation. *Advances in Pain Research and Therapy*. Vol. 3, Ed. Bonica et al. Raven Press, N.Y., 1979. p. 569-585. See Abstract on page 83.
2. Eriksson, M., Sjolund, B., and Sundbarg, G. Pain relief from peripheral conditioning stimulation in patients with chronic facial pain. *J. Neurosurg.* 61:149-155, 1984. See Abstract on page 84.
3. Chapman, C.R., Chen A.C., and Bonica, J.J. Effects of intrasegmentalelectrical acupuncture on dental pain: evaluation by threshold estimation and sensory decision theory. *Pain*. Vol. 3, Biomedical Press, pp 213-227, 1977. See Abstract on page 86.
4. Sjolund, B., and Eriksson, M. Endorphins and analgesia produced by peripheral conditioning stimulation. *Advances in Pain Research and Therapy*. Vol. 3, ed. Bonica Raven Press, N.Y. 1979. See Abstract on page 87.
5. Chapman R., Wilson, M., and Gehrig, J. Comparative effects of acupuncture and transcutaneous stimulation on the perception of painful dental stimuli. *Pain*. Vol. 2, p 265-283, Amsterdam 1976. See Abstract on page 87.
6. Andersson, S.A., Holmgren, E., and Roos, A. Analgesic effects of peripheral conditioning stimulation - II. importance of certain stimulation parameters. *Acupuncture and Electro-Therapeut. Res. mt. J.* Vol. 2, No. 3, pp 237-246. Great Britain 1977. See Abstract on page 88.
7. Andersson S.A., and Holmgren, E. Analgesic effects of peripheral conditioning stimulation - III. Effect of high frequency stimulation; segmental mechanisms interacting with pain. *Acupuncture and ElectroTherapeut. Res. mt. J.* Vol. 3, pp 23-36, Great Britain 1978. See Abstract on page 89.
8. Andersson, S.A., and Holmgren, E. On acupuncture analgesia and the mechanism of pain. *American J. of Chinese Medicine*. Vol. 3, No 4, pp 311-344, 1975. See Abstract on page 91.
9. Sjolund B., Terenius, L., and Eriksson, M. Increased cerebrospinal fluid levels of endorphins after electro-acupuncture *Acta Physiol. Scand.* 100: 382-384, Sweden 1977. See Abstract on page 93.
10. Cheng, R.S., and Pomeranz, B.H. Electro-acupuncture analgesia is mediated by stereospecific opiate receptors and is reversed by antagonists of type I receptors. *Life Sciences*. Vol. 26, pp 631 -638, 1980. See Abstract on page 93.
11. Reichmanis, M., and Becker, R.O. Relief of experimentally induced pain by stimulation at acupuncture loci: a review. *Comparative Medicine East and West*. Vol. 5, No 3-4, pp 281-288, 1977. See Abstract on page 94.
12. Andersson, S.A., Pain control by sensory stimulation. *Advances in Pain Research and Therapy*. Vol. 3 Ed. John J. Bonica et al, 1979. See Abstract on page 94.
13. Mannheimer, J.S., and Lampe, G.N. *Clinical Transcutaneous Electrical Nerve Stimulation*. Philadelphia: F.A. Davis, p 341, 1984. See Abstract on page 95.
14. Hansson, P., and Ekblom, A. Transcutaneous electrical nerve stimulation (TENS) as compared to placebo TENS for the relief of acute oro-facial pain. *Pain*. Vol. 15, pp 157-165, 1983. See Abstract on page 95.
15. Terezhalmay, G.T., Ross, G.R., and Holmes-Johnson, E. Transcutaneous electrical nerve stimulation treatment of TMJ-MPDS patients. *Ear, Nose, and Throat Journal*. Vol. 61, pp 22-28, December 1982. See Abstract on page 96.
16. Phero, J.C., Raj, P.P., and MacDonald, J.S. Transcutaneous electrical nerve stimulation and myoneural injection therapy for management of chronic myofascial pain. *The Dental Clinics of North America*. Vol. 31, No. 4, pp 703-722, October 1987. See Abstract on page 97.

SECTION 2: STUDIES THAT DOCUMENT NEURAL MEDIATION OF MYOMONITOR STIMULUS

1. Jankelson, B., Sparks, S., and Crane, P., Neural conduction of the Myo-monitor stimulus: A quantitative analysis. *J. Prosthetic Dentistry*. Vol. 34, No. 3, pp 245-253, September 1975. See Abstract on page 99.

2. Fujii, H. Evoked EMG of masseter and temporalis muscles in man. J. of Oral Rehabilitation. Vol. 4 pp 291-303, 1977. See Abstract on page 102.
3. Fujii, H., and Mitani, H. Reflex responses of the masseter and temporal muscles in man. J. of Dental Research. Vol. 52, No. 5, pp. 1046-1050, 1973. See Abstract on page 104.
4. Choi, B. On the mandibular position regulated by Myo-monitor stimulation. J. Japanese Prosthetic Dentistry. Vol. 17 pp 73-96, 1973. See Abstract on page 106.
5. Williamson, E., and Marshall, D. Myomonitor rest position in the presence and absence of stress. Facial Orthopedics and Temporomandibular Arthrography. Ed. Williamson, Vol. 3, No: 2, 1986. See Abstract on page 106.

SECTION 3: STUDIES THAT DOCUMENT HISTOCHEMICAL EFFECT OF LOW FREQUENCY TENS

1. Dixon, H.H., and Dickel, H.A. Tension headache. J. Northwest Medicine. Vol. 66, pp. 817-820, Sept. 1967. See Abstract on page 107.
2. Dixon, H.H., and O'Hara, M. Fatigue contracture of skeletal muscles. J. Northwest Medicine. Vol 66, pp-813-816, Sept. 1967. See Abstract on page 108.
3. Rodbard, S., and Pragay, E.B. Contraction frequency, blood supply, and muscle pain. J. of Applied Physiology. Vol. 24, No. 2, Feb. 1968. See Abstract on page 108.
4. Rasmussen, O.C., Bonde-Peterson, F., Christensen, L.V., and Moller, E. Blood flow in human mandibular elevators at rest and during controlled biting. J. Oral Biology. Vol. 22, pp 539-543, 1977. See Abstract on page 109.
5. Lasagna, M., and Orland, C. Modificazione die flussi ematici muscolocutanei indotta dallo stimolazione neurale transcutanea ischemia e dolore nella patologia oclusale. J. Odontostomatologia e Lymplantopratesi. 1986. See Abstract on page 109.
6. Thomas, N.R. Spectral analysis in the pre- and post-TENS condition. Presented International College of Cranlo-Mandibular Orthopedics, Oct. 1986. See Abstract on page 111.

SECTION 4: STUDIES DOCUMENTING MYO-MONITOR EFFICACY

1. Pantaleo, T., Prayer-Galletti, F., Pini-Prato, G., and Prayer-Galletti, S. An Electromyographic study in patients with myo-facial pain-dysfunction syndrome. Bull. Group. mt. Rech, sc. Stomat. et Odont. Vol 26, pp. 167-179, 1983. See Abstract on page 113.
2. Wessberg, G.A., and Dinham, R. The Myo-monitor and the myo-facial pain dysfunction syndrome. J. Hawaii Dental Assoc. Vol. 10, No. 2, pp. 10-13, 1977. See Abstract on page 116.
3. Wessberg, G.A., Carroll, W.L., Dinham, R., and Wolford, L.M. Transcutaneous electrical stimulation as an adjunct in the management of myofascial pain dysfunction syndrome. J. of Prosth. Dent. Vol. 45, No. 3, pp. 307-314, 1981. See Abstract on page 117.
4. Boschiero, R., Fraccari, F., and Pagnacco, O. Analysis of the results of the use of the myo-monitor in patients with reduced mouth openings. J. Mm. Stomatologica. Vol. 35, pp. 857-864, Sept. 1986. See Abstract on page 118.
5. Konchak, P., Thomas, N., Lanigan, D., and Devon, R. Freeway space measurement using mandibular Kinesigraph and EMG before and after TENS. The Angle Orthodontist. Oct. 1988, pp. 343-350. See Abstract on page 119.
6. Bazzotti, L. Electromyography tension and frequency spectrum analysis at rest of some masticatory muscles, before and after TENS. Electromyogr Clin Neurophysiol. 1997 Sep; 37(6):365-78. See Abstract on page 121.
7. Eble, O.S., Jonas, I.E., and Kappert, H.F. Transcutaneous electrical nerve stimulation (TENS): its short-term and long-term effects on the masticatory muscles. J. Orofac Orthop. 2000; 61(2):100-11. See Abstract on page 121.

STUDIES THAT DOCUMENT THE EFFICACY OF LOW FREQUENCY TENS

LOW FREQUENCY (ACUPUNCTURE LIKE) TENS = MYO-MONITOR

LOW FREQUENCY T.E.N.S.

INTRODUCTION

The A.D.A. draft status report on Devices for the Diagnosis and Treatment of Temporomandibular Disorders sites a single study by Block and Laskin as evidence that TENS and a placebo effect elicited similar results. Block and Laskin used a pulse generated stimulator with peak amplitude from 0-76 ma (500 ohm load) and a pulse rate of 12-100 pulses/sec. Block and Clark clearly state that the modality employed in their study is based on the concept of stimulation that increases input into the spinal gate, thereby altering pain awareness by inhibiting pain sensation.

It must be noted that this is an entirely different modality than low frequency, 0.5 Hz-4 Hz, acupuncture-like TENS. The well controlled studies of Chapman, Anderson, Erickson, Sjolund, Bonica, Chang, Holmgren and others clearly support the preference of low frequency TENS for treatment of chronic pain disorders. Low frequency acupuncture-like modalities such as the Myomonitor have ample and specific documentation in the medical literature regarding local histochemical and endorphin effects.

Following are controlled studies from the medical and dental literature supporting the efficacy of low frequency (acupuncture-like) TENS. Low frequency TENS has a 0.5Hz • 10Hz frequency parameter. However, most of the studies utilize 0.5Hz to 9.0Hz in the investigations.

Andersson, S.A. Pain control by sensory stimulation. Advances in Pain Research and Therapy. Vol 3, ed. John J. Bonica et al, Raven Press, N.Y. 1979.

Transcutaneous nerve stimulation (TNS) and acupuncture are the main methods for sensory stimulation used in medical practice.

In contrast to acupuncture, TNS is usually given at high frequency (50 to 100 Hz) and with low intensity which is kept well below that giving pain. The subjective sensation is different from that during acupuncture and is described as tingling or vibration. There are no phasic muscle movements, but a slight tonic contraction may occur in muscles close to the stimulating electrodes (Andersson, S.A. 1979). The afferent nerve fiber discharge consists of a continuous firing in low and high-threshold afferents depending on the intensity.

Another relevant parameter of the sensory stimulation is its frequency. Pain threshold measurements have shown that low frequency (1 to 4 Hz) gives a gradual and slow increase of the threshold which remains elevated during a long-lasting stimulation and returns slowly in the poststimulation period. These effects contrast strongly the transient pain threshold increase observed during stimulation at high frequency (100 Hz). In spite of a continuous stimulation at high intensity, the pain threshold declines to the control level. It should also be noted that the effect is more localized than that at low frequency. Thus low-frequency stimulation of the cheeks increases the threshold of the teeth in both the upper and lower jaws, whereas high-frequency stimulation at the same location and intensity gives a transient effect only in the incisive and canine teeth of the upper jaw.

It should also be noted that the most common type of conditioning stimulation TNS, often has a pronounced effect on chronic pain, but the pain threshold (is) unchanged or increased only transiently at the start of the stimulation. The pain threshold measurements refer to experimental pain mediated via A delta fibers, at least when electrical stimuli are used as tests. Chronic pain may be due to activity in C fibers, and it remains to be determined whether the threshold for C fiber-mediated sensations is increased during high-frequency stimulation.

When the low frequency, high-intensity stimulation is modified into repetitive, high-frequency bursts, the conditioning is less distressing and pain conditions not relieved by high-frequency stimulation can be alleviated. (Eriksson, M. 1976.)

Substances with morphine-like effects, endorphins, appear to be transmitters in the descending control systems, and morphine exerts its analgesic effect partly by activation of such systems (Mayer, D.J. 1976), but it has also a direct action on the spinal cord (Besson, 1973, Fields, 1978, Kitahata, 1974, LeBars, 1976, Zieglgansberger 1976). Administration of naloxone, a specific narcotic antagonist, inhibits the analgesic effect both of electrical stimulation of the brainstem and of morphine. (Fields 1978)

There is evidence that low-frequency stimulation (acupuncture) activates descending control systems. Naloxone decreases or eliminates the analgesia produced by classic needle acupuncture in healthy subjects (Mayer, 1975) Moreover, naloxone inhibits the pain relief elicited by low-frequency electrical stimulation in patients with chronic pain but it does not counteract analgesic effects produced by high-frequency sensory stimulation. (Sjolund 1976) A low concentration of endorphins is often found in the cerebrospinal fluid (CSF) of patients with chronic pain of somatic origin as compared to pain of psychogenic origin (Almay 1978). Low-frequency electrical stimulation producing pain relief increases the CSF concentration of endorphins. (Sjolund 1977). The counteraction by naloxone of the pain relief after acupuncture could thus be due to an effect on the endorphin release by the stimulation.

A pain inhibition center, possibly including the brainstem structure producing analgesia by direct stimulation, receives input from a variety of afferents ranging from large non-pain fibers to pain afferents. Stimulation of these afferents increases the output from the pain inhibition center with blockade of the transmission at different levels of the pain pathway. The pain inhibitory mechanism has endorphins as transmitters in some link. The differences in the characteristic of the pain relief elicited by different types of sensory stimulation appears to reflect at least two different pain inhibitory mechanisms.

Eriksson, M., Sjolund, B. and Sundborg, G. Pain relief from peripheral conditioning stimulation in patients with chronic facial pain. *J. Neurosurg.*, 61:149-155, 1984.

Departments of Clinical Neurophysiology and Neurosurgery, University Hospital, Lund, Sweden.

In a prospective study, 50 consecutive patients, referred to a pain treatment unit for surgery to alleviate various forms of facial pain, were all given transcutaneous nerve stimulation (TNS) therapy and followed for 2 years. Of the 44 patients remaining at the 2-year follow-up review, 20 (45%) reported satisfactory analgesia from conventional or acupuncture-like TNS. The latter technique markedly improved the overall results. No serious side effects were seen. Atypical facial pain of known etiology responded best to treatment, but satisfactory relief was often produced with tic douloureux. Duration of the pain condition as well as sex of the patient were predictors of treatment results. It is concluded that TNS therapy represents a valid alternative to surgery when pharmacological therapy fails, especially in the elderly and in patients with atypical facial pain.

Patients with chronic so-called intractable facial pain may present management problems. This is true for typical trigeminal neuralgia (tic douloureux) as well as for atypical forms of facial pain. (Anthony, M 1974, Loeser, J.D. 1977, Rasmussen 1965)

A different line of therapy has developed from the hypothesis that trigeminal neuralgia is a result of vascular compression of the trigeminal nerve root. (Dandy, W.E. 1934)

In cases of atypical facial pain, (Gregg, J.M. 1978, Rushton, J.G. 1959) with or without an identifiable organic cause, antiepileptic drugs are generally ineffective. Alcohol injections or surgery, even if giving temporary relief, may later result in a considerable worsening of the condition. (Gregg, J.M. 1975, Rasmussen, P. 1965). Conventional analgesics may be useful when there is an organic cause for the disorder, and tricyclic antidepressant drugs may help when there is not. (Anthony, M. 1974) The available therapeutic methods, however, leave many patients unaided and substantially handicapped by their chronic facial pain.

During the last decade, treatment by conditioning stimulation of peripheral nerves has become increasingly used for patients with acute and chronic pain conditions. (Loeser, J.D. 1975, Long, D.M. 1976, Wall, P.D. 1967) A long-term follow-up study of the effect of two types of transcutaneous electrical nerve stimulation (TNS) showed that, after 2 years, 31% of patients referred to a neurosurgical department still experienced useful analgesia from daily TNS treatment. (Eriksson, M.B.E. 1979) Among these successfully treated patients with chronic pain were several who had previously had intractable facial pain, some of whom had to use a newly developed TNS technique (acupuncture-like TNS)(Eriksson, M.B.E. 1976) to obtain pain relief.

Apart from the need for alternative therapeutic methods among patients with intractable facial pain, it seemed of great interest for the evaluation of the TNS techniques to test and follow a group of patients suffering from chronic pain that was less varied as to type and location than in previous studies. We therefore initiated a prospective long-term follow-up study of 50 patients with intractable facial pain, treated with conventional (Ihalainen, U., 1978, Wall, P.D. 1967) or acupuncture-like (Ericksson, M.B.E. 1976, Eriksson, M.B.E., 1979). The facial pain conditions treated represent two types of pain: namely, acute intermittent (tic douloureux) and chronic continuous (atypical facial pain). The study and the results obtained are the subjects of this report.

The series included 50 consecutive patients with intractable facial pain who were referred to the Department of Neurosurgery at Lund University Hospital for surgery. Twenty-one patients had been classified as having tic douloureux. To comply with the diagnostic criteria, the pain had to be: 1) truly paroxysmal; 2) unilateral; 3) provokable by non-nociceptive facial stimuli; 4) confined to the innervation area of one, two, or three trigeminal branches; and 5) not associated with sensory or other neurological deficit.

Twenty-nine patients did not fulfill the criteria . . . tic douloureux and will be considered here as having "atypical facial pain." In 18 of these patients the pain resulted from accidental or surgical trauma (11 patients), cerebrovascular disease, (five patients), or herpes zoster ophthalmicus (two patients).

If after the first 2-week trial period, there was no significant pain relief, the patient was instructed how to use the stimulator for acupuncture-like TNS. The positive electrode was then placed in front of the ear and the negative electrode over the forehead, cheek, or chin. The stimulator was set for a train (7 pulses at 100Hz) given at a repetition rate of 1.5 to 2 Hz. (Eriksson, 1976, Eriksson, 1979) and the electrodes adjusted so that visible muscle contractions were produced in the area of pain (Fig. 2). If, after another 2-week trial period at home, there was still no report of significant pain relief, the TNS trial was recorded as a failure. If stimulation treatment was reported to reduce the intensity and frequency of pain paroxysms, or produced useful relief in patients with non-paroxysmal atypical intractable facial pain, the patient was instructed to continue with the treatment and was seen again 2 months later.

After 3 months of treatment, 16 (32%) of the 50 patients experienced successful or moderately successful pain relief with conventional TNS only. (Fig. 3) Of the 34 patients who did not benefit from conventional TNS, acupuncture-like TNS proved to be satisfactory in 13 patients. Thus, in all, 29 (58%) of the 50 patients experienced pain relief from TNS. Twenty patients used stimulation only and were considered a success, and nine patients who added small amounts of adjuvant pharmacotherapy were considered a moderate success.

There was no significant difference in treatment success between patients with tic douloureux (11 of 21 patients) and atypical facial pain (18 of 29 patients). However, significantly ($0.025 < p < 0.05$) better results were obtained in patients who had atypical facial pain with a known organic cause as compared to all other patient groups (Table 1). The median duration of pain for all patients was 6 years.

The success rate of TNS was significantly ($0.025 < p < 0.05$) higher among patients with a pain history of less than 6 years than in the group with a longer history of facial pain. (Fig. 4) The mean duration of pain was similar among men (7 years) and women (8 years).

The present study has confirmed our initial observations (Eriksson 1979) that TNS may be a worthwhile choice of therapy in patients with intractable facial pain. After about 3 months of TNS therapy, about half of the patients with tic douloureux, whose symptoms were often of considerable duration, and two-thirds of those with atypical facial pain achieved satisfactory pain relief.

Even after 2 years, 45% of the 44 patients remaining in the study used TNS regularly and experienced satisfactory relief. No serious side effects were seen. All of these patients had severe conditions and were judged to be failures as regards conservative treatment; however, the results of this study show that TNS therapy may well be a relevant alternative to surgical procedures. This may be so for elderly tic douloureux patients, in whom surgical risks are more serious, (Apfelbaum 1977, Jannetta 1980) and for all patients with atypical facial pain, where surgical results are not encouraging. (Gregg, 1978, Rasumssen, 1965)

Interestingly, the newly introduced technique of acupuncture-like TNS (Eriksson, 1976) seems to have improved the results considerably as compared to the use of conventional TNS. (Wall 1967). This may well explain why our results with intractable facial pain are superior to those reported by others; (Gregg, J.M. 1978, Magora 1978) but see the report of Ihalainen and Perkki.(Ihakaubebm, U.P. 1978) The treatment success seen after 2 years in this study (45%) is higher than that reported by us in a previous group of patients consecutively referred for chronic pain to the same pain treatment unit. (Eriksson 1979). One possible explanation for this difference is the relative ease with which coarse nerve bundles in the facial region are stimulated as compared to the technique in many other body areas. Another explanation may be that the pain conditions were well defined and neurogenic, (Sjolund, 1979) and a third suggests that psychogenic factors are less predominant in this group. (Neilzen, S. 1982).

Chapman, C.R, Chen, A.C., and Bonica, J.J. Effects of intrasegmental electrical acupuncture on dental pain evaluation by threshold estimation and sensory decision theory. *Pain*, 3:213-227, 1977.

SUMMARY

The effect of 80 min of low frequency (2 Hz) electric acupunctural stimulation at facial sites on the perception of induced dental pain was evaluated using both pain threshold and sensory decision theory (SDT) procedures. The demonstration of a 187% increase in threshold over a 20 min period of acupunctural stimulation replicated earlier work by Swedish investigators. SDT Analyses indicated that the threshold increase reflected a relatively pure sensory change with no significant modification of response bias.

INTRODUCTION

Studies evaluating the effects of acupunctural stimulation on pain evoked from tooth pulp by electrical current have yielded positive findings. Analgesic effects have been statistically significant, but weak, in most studies which have examined the responses of subjects receiving acupuncture at the hoku site on the hands (Chapman 1975, Chapman 1976, McBurney 1975). A more powerful effect has been reported (Andersson 1973), and repeatedly replicated (Andersson 1973, Andersson 1975, Holmgren 1975), by Andersson, Holmgren, and their associates, who stimulated acupuncture sites in the second trigeminal nerve division in addition to the hoku points. They observed large increases in pain threshold over time with stimulation, which paralleled rather closely the report of Chinese investigators employing potassium iontophoresis dolorimetry (Research Group of Acupuncture Anesthesia, Peking Medical College 1973).

METHODS

SUBJECTS

Twenty male undergraduate students, ranging in age from 18 to 26 years and in good physical and dental health, served as paid volunteers. None of the subjects were using analgesic or psychotropic drugs, and all were fully informed of the methods and aims of the investigation. Ten volunteers were assigned to an acupuncture test group while the remainder served as control subjects. Controls were tested after acupuncture subjects in order to properly match them to the conditions of the experimental group

RESULTS

Fig. 1 presents the threshold values obtained for the treatment and control groups at 0, 10, 20 and 80 min. It is evident that acupuncture subjects showed a gradual increase in threshold, which reached a relatively stable state after 20 min. The 80 min measure was obtained after the current was turned off and the needles were removed, thus sensory masking or distraction. The control group showed no noteworthy changes in threshold over time. An analysis of variance was used to compare the pain thresholds of the two groups of subjects over time, and Table II provides a breakdown of this analysis.

Response bias, or willingness to report the dental stimulation experienced as painful, was evaluated by a non-parametric index introduced by Hodos (Hodos 1970) at category VFP on the rating scale. This category represented the point on the response scale at which subjects began identifying the stronger stimuli as painful events rather than as sensations. The Hodos index, termed "percent bias" ranges from -100.00 (no bias against calling the stimuli painful) to +100.00 (total bias against calling them painful) with 0.00 indicating no bias whatsoever. The mean percent bias value for the control group was 5.00 (S.D. = 81.04) while for the acupuncture group, it was 46.89 (S.D. = 59.08), but these values were not significantly different, $t = 1.274$, $P > 0.05$. These findings indicate that the increase in pain threshold that occurred with acupunctural stimulation did, in fact, reflect a decrease in sensory sensitivity to tooth pulp shocks. Response bias played a trivial role in the treatment-induced threshold increase.

DISCUSSION

In spite of differences in equipment, procedure, site of acupunctural stimulation, and cultural context, we have replicated the dental acupuncture analgesia phenomenon reported by Andersson and Holmgren (Andersson 1973). Intense electrical stimulation at 2-3 Hz over an 80 min period yielded a gradual increase in dental pain thresholds which reached a relatively stable state after approximately 20 min. An SDT analysis of the discrimination tasks involving high intensity, low intensity, and blank stimuli demonstrated that the pain threshold increase reflected a reduction in sensory sensitivity. There was no significant change in response bias or willingness to call the stimulation experienced painful.

The apparent proclivity of dental structures to respond to acupunctural stimulation when cutaneous tissues do not, may be due to morphological or neurological differences in skin and teeth or to unique properties of the trigeminal system or its projection to the brain stem.

Sjolund, B.H., and Eriksson, M. Endorphins and analgesia produced by peripheral conditioning stimulation. *Advances in Pain Research and Therapy*. Vol 3, ed. John J. Bonica, et al. Raven Press, New York, 1979.

ACUPUNCTURE - LIKE TNS

Chiang et al. (Chiang 1973) claimed that impulses from deep afferents were necessary to elicit acupuncture analgesia. Andersson and co-workers (Andersson 1973, Andersson 1976, Sjolund, this volume) found that a stimulation strength giving forceful muscle contractions in the facial musculature was necessary for the rise in tooth pain threshold. They also found that the pain threshold increase was induced even more readily with stimulation via surface electrodes than via needles, probably because the surface electrodes allowed more current to be passed (Andersson 1973).

This type of stimulation, acupuncture-like low-frequency TNS, reduced the current necessary to elicit muscle contraction to half or two-thirds of the single shock values and was tried whenever our chronic pain patients did not experience analgesia from conventional high-frequency TNS. The compiled long-term results of stimulation treatment we then improved by about 40% (Eriksson 1976, Eriksson 1979).

INFLUENCE OF NALOXONE

From the present results it thus seems as if the acupuncture-like (lo-) TNS acts through links utilizing endorphins whereas conventional (hi-) TNS produces analgesia via some other mechanism.

ENDORPHIN MEASUREMENTS

When the concentrations of these endorphin fractions were measured in the cerebrospinal fluid of our chronic patients before (Fig. 3, C) and after (Fig. 3, EAP) acupuncture-like TNS, there was a systematic increase of the fraction I concentration in lumbar cerebrospinal fluid of those patients receiving stimulation of lumbar afferents (Sjolund 1977, unpublished; Fig. 3). This confirms the results on naloxone administration and in addition points to a local release and action of the endorphins at the spinal level during acupuncture-like TNS (see Duggan 1976, Yaksh 1976). With conventional TNS, no increase of endorphin concentrations has been seen in pilot experiments (L. Terenius, personal communication).

Chapman, C., Richard, W., Michael, E., and Gehrig, J.D. Comparative effects of acupuncture and transcutaneous stimulation on the perception of painful dental stimuli. *Pain*, 2:265-283, 1976.

SUMMARY

The effects of acupunctural stimulation on the perception of induced dental pain were compared with those of placebo acupuncture and transcutaneous electrical stimulation (TES) at an acupuncture site. Each of 4 groups of 15 subjects received one of the following treatments: acupuncture, placebo acupuncture, TES, or control conditions. Every subject was tested twice, once in a baseline session and on another day in a test session. Four levels of painful dental stimuli were delivered repeatedly and in random order to each subject in each session, who rated the perceived intensity of each stimulus on a pain category scale.

All three treatment groups showed a significant reduction in magnitude of stimulus ratings after treatment. A Sensory Decision Theory analysis of the data was employed to assess the sensory sensitivity of each subject to each of 4 levels of dental stimulation and the willingness of the subject to label the strongest stimulus as painful. Acupuncture and TES groups showed a small but significant sensory analgesic response to treatment and a significant reduction in willingness to identify the strongest stimulus as painful when contrasted to controls, but placebo acupuncture subjects failed to show significant change on either of the response measures. The effects of acupuncture were most pronounced at the lowest level of stimulation, while TES affected the perception of all levels of dental stimuli. The observed effects appeared to be small, reliable, and dependent on the stimulation of a particular anatomical locus.

METHODS

Four treatment groups were established: acupuncture, transcutaneous electrical stimulation (TES) at an acupuncture site, placebo acupuncture, and control. Subjects in each of these groups were tested twice on two separate days to provide a separate set of baseline and test measurements for each group.

It has been argued convincingly that acupuncture analgesia studies cannot be run double blind (Mark 1973), but is nonetheless desirable to reduce experimenter expectation effects as far as possible. Accordingly, a pseudo-double blind procedure was established in which a visual screen was used to ensure that neither the subject nor the experimenter could see which treatment was being administered to the subject during the test session. Of course, tactile cues were still available to the subject.

RESULTS

While SDT analyses are of intrinsic value, it is of interest to relate them to observable pain behavior. In this study, the perceivable behaviors were the ratings assigned to the dental stimuli, and the analgesic effects evident to an observer were the reductions in the magnitude of rating judgments given to the stimuli. In order to relate changes in d' and C4 to decreases in rating values, multiple regression methods were employed.

Since change scores indicated behavioral changes over sessions, they reflected treatment effects in the acupuncture and TES groups. It was of interest to ask how much of the treatment-induced change in pain ratings could be accounted for on the basis of change in sensory sensitivity and response bias. Multiple regression methods provided a way of estimating this and of evaluating the relative importance of sensory and bias factors.

In brief, this was done by using d' and C4 as predictors in order to create hypothetical estimates of mean rating change values for each subject. The accuracy of such predictions was evaluated by comparing the values predicted on the basis of d' and C4 with the actual mean rating measures. The results obtained indicated that the two SDT measures taken together were meaningful as predictors of the mean rating changes in the treatment groups. This implied that the observable behavioral changes in ratings reflected unobservable changes in sensory abilities and attitude toward reporting the stimuli as painful, in addition to inevitable measurement error.

In order to evaluate whether d' or C4 was most influential in determining the rating behaviors of the subjects, the proportion of variability among the rating change scores which could be accounted for by d' changes measures was estimated, and the same calculation was followed for the C4 values.

DISCUSSION

The data obtained from the acupuncture subjects have provided a general replication of the sensory hypalgesic effect reported by Chapman et al. (Chapman 1975). However, in the first study the d' analgesic effects appeared to be consistent in magnitude across stimulus levels but this was not replicated here. In Table II it is evident that such changes were greatest at the lowest level of stimulus intensity, and small or negligible at the higher levels. The results of the multiple regression analyses have supported this observation, indicating that acupuncture's effects were minimal for higher levels of stimulation. As a check, a multiple regression analysis similar to that described above was carried out on the acupuncture data collected by Chapman et al. (Chapman 1975). The essential results, reported in Table V, are highly consistent with those obtained in this study. Thus, while d' scores changed substantially at all levels of stimulus intensity in the earlier study, only the changes at the lower intensity were significantly related to changes in pain ratings. These findings indicate that acupuncture's analgesic effects were in fact quite similar to those of 33% nitrous oxide.

Interestingly, a similar result was obtained for subjects undergoing TES at an acupuncture site, and this agrees with the report of Andersson et al. (Andersson 1973) who observed a slightly greater increase in pain threshold with TES than with acupuncture. These observations suggest that the analgesic effects reported here were not dependent on the stimulation of deeper structures. Since the placebo acupuncture group showed no positive responses to treatment, it would seem that acupuncturally induced dental hypalgesia requires stimulation of specific loci.

Andersson, S.A., Holmgren, E., and Roos, A. Analgesic effects of peripheral conditioning stimulation - U. Importance of certain stimulation parameters. *Acupuncture & Electro-Therapeut. Res. mt. J.*, Vol 2, No. 3 & 4, pp. 237-246, 1977.

ABSTRACT

The pain threshold effects in teeth, generally described in a previous paper, are related to certain parameters of the conditioning stimulation. A strong low frequency stimulation (2/sec) giving pronounced beating sensations and powerful muscle contractions is needed to produce any significant threshold increase and no changes of the threshold were found at low intensities.

DISCUSSION

The present results show some important features of the pain threshold effects produced by low frequency conditioning stimulation. Thus, the degree of the threshold increase is mainly related to a relatively segmental location of the stimulating electrodes and to the intensity of the conditioning stimuli. If these parameters are kept constant the effect is also reproducible.

It can, however, be stated that conditioning stimulation of the maxillar branch of the trigeminal nerve influences the pain threshold of the teeth similarly in both the upper and lower jaw, the latter being innervated by the mandibular branch of the trigeminal nerve and thus not strictly segmental to the location of the stimulation electrodes.

The results of the present study give further support to the idea that basic physiological mechanisms are involved in the pain threshold effects of the conditioning stimulation (Andersson et al, 1976). If psychological suggestive components were most important, certain effects on the pain threshold would have been expected already at low intensities of the stimulation (levels A-C). The absence of effects, in spite of the sensations evoked by the electrical pulses, indicates that a suggestive component is not of any significant importance in the present experimental situation. This conclusion is also supported by the reproducibility of the effects at constant stimulation intensities and by the possibility of also producing threshold increases in primarily unresponsive subjects when they have been sufficiently acquainted to the experimental situation to allow an appropriate intensity of the conditioning stimulation.

The above mentioned observations suggest that the activation of large diameter afferent fibres conveying the information from low threshold cutaneous afferents is not sufficient to influence the pain threshold at a low stimulation rate. The pain threshold seems to increase only when the subjective magnitude of the beating and observed muscle contractions exceed a certain level. Apparently the conditioning stimulation must activate not only low threshold afferents but also fibres with higher thresholds. The present finding of a pronounced increase of pain threshold only at intensities giving rise to powerful muscle contractions, suggests that activation of muscle afferents is of importance in obtaining an increase of the pain threshold.

Andersson, S.A., and Holmgren E. Analgesic effects of peripheral conditioning stimulation - II Effect of high frequency stimulation; Segmental mechanisms interacting with pain. *Acupuncture & Electro-Therapeut. Res. mt. J.*, Vol 3, pp 23-36, 1978.

ABSTRACT

The effects on the pain threshold of teeth during conditioning stimulation with different frequencies were studied in volunteers. High intensity stimulation of the cheeks at 100/sec produced at onset a transient increase of the pain threshold essentially restricted to teeth of the upper jaw. No increase of the pain threshold was obtained by stimulation at 100/sec of the hands. Conditioning with 10/sec of the cheeks gave a rapid rise of the threshold followed by a gradual increase, but during prolonged conditioning the threshold declined. Stimulation with 2/sec produced a slow gradual increase of the threshold which remained at high level throughout a longlasting period. The after-effect was more pronounced at stimulation with 2/sec as compared to 10/sec. The segmental mechanisms of pain are discussed and it is suggested that the pain afferents should be considered as a subgroup of the flexor reflex afferents and that the segmental connexions of the pain afferents are subject to similar pre- and postsynaptic segmental and supraspinal inhibitory mechanisms as those known to exist with regard to the transmission from the flexor relex afferents to the flexor motoneurons. The effect of low frequency, high intensity conditioning stimulation on the pain threshold and on acute pain is discussed in relation to an increased inhibition at the input stage by feedback systems via the brain stem. High frequency stimulation is suggested to influence the pain threshold and chronic pain mainly due to pre and postsynaptic inhibition elicited by activity in primary afferents at the segmental level.

INTRODUCTION

A method of low frequency (1-3/sec) conditioning stimulation has been developed for Chinese acupuncture. Stimulation can be applied either through manipulation of needles or through low frequency high intensity electrical stimulation via either needles or surface electrodes. Both Chinese (cf. Kaada et al, 1974) and Western reports (Holmdabl, 1973; Mann et al., 1973; Omura, 1973, 1975) argue that this method of stimulation has a relieving effect in acute as well as chronic pain conditions. Electrical stimulation via needles or surface electrodes also produces a marked increase of the pain threshold (Andersson et al., 1977a). In contrast to the almost immediate effect of high frequency stimulation, the onset of the pain relief is gradual, lasting 15-20 min, and the after-effect is longlasting with a slow gradual return of the pain. The pain threshold also showed a gradual increase during low frequency electrical stimulation and a gradual decline in the post-stimulation period (Andersson et al., 1977a). Thus, there is a marked similarity between the time course of the clinical analgesia and the pain threshold increase during low frequency

conditioning stimulation. Another similarity between the analgesia and the pain threshold increase is found in the high intensity required to obtain these effects during low frequency stimulation (Anderson et al., 1977c).

A pronounced pain threshold increase is obtained only by an intensity just below that producing pain. The importance of intense stimulation has been stressed in reports of surgical analgesia induced by conditioning stimulation (Peking Acupuncture Anaesthesia Co-ordinating Group, 1973; Section of Thoracic Surgery, Peking 1973). Thus pain relief during low frequency stimulation appears to be produced by recruiting another type of afferent fibres as compared with high frequency stimulation which is already effective at a moderate intensity activating low threshold mechano-receptors. The Analgesic effects of high and low frequency conditioning stimulation also differ with regard to their distribution. During low frequency conditioning, non-segmental effects have been stressed, particularly in Chinese reports, and it has been claimed that a generalized analgesia and pain threshold increase can be obtained by manipulation of needles at certain points. This effect contrasts strongly with the closely segmental pain relief found during high frequency stimulation and is also in conflict with the results in a previous report (Andersson et al., 1977c) which showed that the pain threshold increases mainly in regions related to those exposed to conditioning stimulation, i.e. mainly cheek stimulation increased the pain threshold of teeth. Some Chinese reports emphasize, however, the segmental stimulation is of importance to obtain analgesia sufficient for surgery (Hua Shan Hospital of Shanghai, 1973; Shanghai First People's Hospital, 1973).

Thus, large differences are found in the Analgesic effects of conditioning stimulation with high and low frequencies which suggests that the mechanisms interacting with the sensations of pain are different.

DISCUSSION

GENERAL CONSIDERATIONS

The slowly increasing and longlasting pain threshold changes produced by a conditioning stimulation of 2/sec were completely different from those produced at high frequencies. Stimulation at 100/sec induced an increase of the threshold almost exclusively in teeth into which the sensation of dull pain projected, and the threshold decreased rapidly during the continued conditioning. The threshold effect was obtained only at a high intensity. During continuous stimulation at a constant intensity the test subjects reported a decrease in the sensation of dull pain which approximately paralleled the decrease of the tested pain threshold. Stimulation at 10/sec appeared to produce changes of the threshold with characteristics of the effect from stimulation at 2/sec and at 100/sec. The rapid increase and fall of the threshold at the start and end of the 10/sec conditioning may be related to the transient effect at 100/sec. These threshold changes were followed by a slow increase and decrease respectively at the onset and end of the conditioning which are typical characteristics of the effects of stimulation at 2/sec.

SUPRASPINAL CONTROL

The transmission from the FRA both to flexor motoneurons and to ascending pathways, which may be involved in the transmission of pain, is tonically depressed from supraspinal structures as revealed in acute experiments in decerebrate cats (Holmquist et al., 1960). One such pathway is the dorsal reticulospinal pathway which arises in the brain stem and inhibits the transmission in the FRA pathways at an early stage in the interneuronal chain (Engberg et al., 1968a,b). A similar inhibition appears to be exerted on the FRA pathway by a serotonergic descending system (Engberg et al., 1968c,d) arising in the dorsal raphe nuclei (Dahlstrom and Fuxe, 1965). It has been shown in behavioural experiments that stimulation of certain brain structures, especially in the mesencephalic central grey and in the dorsal raphe nuclei, induces analgesia without other behavioural changes. This holds true for different species such as rat (Mayer et al., 1971; Balagura and Ralph, 1973) and cat (Oliveras et al., 1974). These Analgesic effects may be due to the above mentioned descending inhibitory influences since the brain stem stimulation inhibits discharges, evoked by stimuli considered to be painful, in spinal neurones of lamina V (Oliveras et al., 1974). Stimulation of the orbital cortex also gives inhibition of these cells, an effect assumed to be mediated via the brain stem (Wyon-Maillar et al., 1972). The dorsal raphe nuclei are known to contain serotonergic neurones (Dahlstrom and Fuxe, 1965) and further support of their descending Analgesic influence is the fact that analgesia induced by brain stem stimulation is antagonized by the serotonin synthesis inhibitory p-CPA (Akil and Mayer, 1972). A particularly interesting finding is the need for a long induction time (15-20 min) of this brain stem-induced analgesia (Melzack and Melinkoff, 1974). It is not known at present how the activity in these descending control systems varies during different conditions, neither is the functional significance of the input to these systems established. One possibility is that certain descending pathways are parts of a system which controls the level of excitability at an early stage of certain ascending pathways excited from FRA, including the pain afferents. The similarity in the characteristics of the Analgesic effects elicited by electrical stimulation in certain brain stem nuclei (Meizack and Melinkoff, 1974) and by low frequency conditioning stimulation suggests that essentially the same mechanisms are utilized. As a working hypotheses we assume that 2/sec conditioning stimulation induces a slowly increasing activity in descending control systems which inhibit the transmission of impulses both postsynaptically and presynaptically in the pain pathway. A certain topographical arrangement in the

descending system is also required to account for the close relation between the regions of conditioning stimulation and the pain threshold although some general increase of the efficiency of the inhibitory effect may be present as suggested by the effect on the pain threshold of teeth due to conditioning stimulation of hands (Andersson et al., 1977c).

Support for the hypothesis that low frequency conditioning stimulation interferes with the transmission of activity in the FRA system has been obtained in animal experiments. After conditioning with 2/sec of forelimb nerves or the infraorbital nerves in awake cats the jaw opening reflex, elicited by electrical stimulation of the tooth pulp and considered as an analogue to the spinal flexion reflex (Sherrington, 1917), is depressed in parallel with reduced aversive reactions (Andersson, 1973; Andersson and Holmgren, in preparation). This observation is consistent with a Chinese report that low frequency (1/sec) electro-acupuncture depresses the jaw opening reflex and reduces the cortical potential evoked by electrical stimulation of teeth (Peking Acupuncture Anaesthesia Co-ordinating Group, 1973). In addition, it has been shown that brain stem stimulation at locations known to induce behavioural analgesia also increases the threshold for the jaw opening reflex (Oliveras et al., 1973)

RELATION TO CLINICAL PAIN

The discussed mechanisms of interaction with the sensation of pain are of interest in relation to clinical pain conditions. It is apparent from clinical reports that low and high frequency conditioning stimulation have different influences on acute and chronic pain. Acute pain seems to be relieved by low frequency conditioning stimulation. The time course of this effect is similar to the observed increase of the pain threshold with a long induction time (15-30 min) and longlasting post-stimulation effect. The analgesia is often sufficient to allow surgery. Our findings of an effect on the pain threshold mainly from areas with innervation relatively closely related to that receiving the pain stimulus, are in agreement with a number of recent reports on clinical analgesia during low frequency conditioning. Thus, large similarities seem to exist in the effect on the pain threshold and on clinical pain during conditioning stimulation with low frequencies. It is concluded that the same general pain blocking mechanisms give rise to the pain threshold increase and the clinical analgesia.

Andersson, S.A., and Holmgren, E. On acupuncture analgesia and the mechanism of pain. American Journal of Chinese Medicine. Vol 3, No. 4, pp. 311-334, 1975.

ABSTRACT:

The effect on the experimental tooth pain threshold of conditioning electrical stimulation via needles or surface electrodes applied to the hands and cheeks was studied in 34 dental students. Conditioning stimulation with 2/sec. gave a slowly increasing pain threshold followed by a slow return to the control level in the post-conditioning period. In each individual the amplitude of the threshold increase was reproducible. It was concluded that these effects are not due to motivational but to more basic neurophysiological mechanisms. The pain threshold was increased mainly by segmental conditioning stimulation; segmentally unrelated stimulation gave usually only small effects. Conditioning stimulation with 100/sec. produced only a strict segmental short-lasting effect. Effects with characteristics of both 2/sec. and 100/sec. were obtained by conditioning at 10/sec.

It is suggested that the transmission of impulses from the pain afferents to ascending pathways is controlled at the segmental level by (a) presynaptic inhibition within the group of afferents giving rise to the flexion reflex of which the pain afferents are assumed to be a part; (b) postsynaptic inhibition between alternate pathways excited by flexion reflex afferents; and (c) descending control from supraspinal systems which may utilize similar segmental mechanisms as the primary afferents.

The studies (Andersson, et al, 1975, Andersson, Holmgren and Roos, 1975, Andersson and Holmgren, 1975) summarized in this paper were initiated in order to experimentally elucidate whether a low frequency, electrical peripheral conditioning stimulation can influence the perception of pain. During the initial survey of such effects (Andersson, et al., 1975) using the tooth pulp as a pain test system, it was found that a pain threshold increase could be objectively demonstrated with several characteristics resembling the above mentioned "acupuncture analgesia."

This paper also includes an extensive discussion regarding possible neurophysiological mechanisms underlying the pain threshold effects reported. These mechanisms are also discussed in relation to clinical pain.

MATERIAL AND METHODS

SUBJECTS

The present studies were performed on a group of students in the age group of 21-29 years. In order to avoid a biased selection a full class of 42 dental students was requested to participate in this investigation and all but two volunteered. Six students were excluded because of diseases or pregnancy. The remaining 34 students (15 females and 19 males) were all healthy and did not use drugs.

RESULTS

GENERAL PAIN THRESHOLD EFFECTS

The primary question in this study was: Can electrical conditioning stimulation increase the tooth pain threshold? The initial part of the investigation consisted of a standardized test procedure in which 30 students were studied, 18 with needle electrodes and 12 with surface electrodes (Andersson, et al., 1975). Each threshold value represents the mean value of several measurements of one of the six tested teeth. The control threshold was established two times with an interval of 15 to 30 minutes. The needles or surface electrodes were then applied and the stimulator connected to the electrodes but no electrical conditioning stimulation was given. The pain threshold was measured 15 to 20 minutes later. At time zero condition stimulation started with 2 impulses per second to hands and cheeks and the intensity was slowly increased during the following 10 minutes to a level just below that tolerable to the subject. The pain threshold was measured at intervals of 15 minutes. The stimulation was usually discontinued after 75 minutes, and the threshold was measured several times during the post-conditioning period. Since the duration of the conditioning stimulation period varied slightly, the time scale was reset when this stimulation was discontinued.

SUPRASPINAL CONTROL

The transmission from the FRA both to flexor motoneurons and to ascending pathways, which may be involved in the transmission of pain, is tonically depressed from supraspinal structures as revealed in acute experiments in decerebrated cats (Holmquist, Lundberg and Oscarsson 1960). One such pathway is the dorsal reticulospinal system which arises in the brain stem and inhibits the transmission in the FRA pathways at an early stage in the interneuronal chain (Endberg, Lundberg and Ryall 1968a,b). A similar inhibition appears to be exerted on the FRA pathway by a serotonergic descending system (Endberg, Lundberg and Ryall 1968c,d) arising in the dorsal raphe nuclei (Dahlstrom and Fuxe 1965). It has been shown in behavioral experiments that stimulation of certain brain structures, especially the mesencephalic central grey and the dorsal raphe nuclei, induces powerful analgesia without other behavioral changes. This holds true for different species such as rat (Mayer et al., 1971; Balagura and Ralph 1973) and cat (Oliveras, et al., 1974). These analgesic effects may very well be due to the above mentioned descending inhibitory influences, since the brain stem stimulation inhibits discharges evoked by stimuli considered to be painful in spinal neurons of lamina V (Oliveras, et al., 1974). Stimulation of the orbital cortex also gives inhibition of these cells, an effect assumed to be mediated via the brain stem (Wyon-Maillard, Conseiller and Besson, 1972). The dorsal raphe nuclei are known to contain serotonergic neurons (Dahlstrom and Fuxe, 1965) and further support for their descending analgesic influences is the fact that analgesia induced by brain stem stimulation is antagonized by the serotonin synthesis inhibitor p-CPA (Akil and Mayer, 1972). A particularly interesting finding is the need for a long induction time (15-20 minutes) of this brain stem induced analgesia (Melzack and Melnikoff, 1974). It is not known at present how the activity in these descending control systems varies during different conditions; neither is the functional significance of the input to these systems established. One possibility is that certain descending pathways are parts of a system which controls the level of excitability at an early stage of certain ascending pathways excited from FRA, including the pain afferents. The similarity in the characteristics of the analgesic effects elicited by electrical stimulation in certain brain stem nuclei (Melzack and Melnikoff, 1974) and by low frequency conditioning stimulation suggests that principally the same mechanisms are utilized. As a working hypothesis we assume that 2/sec. conditioning stimulation induces a slowly increasing activity in the descending control systems which inhibits the transmission of impulses both postsynaptically and presynaptically in the pain pathway. A certain topographical arrangement in the descending systems is also required to account for the close relation between the regions of conditioning stimulation and the Analgesic effect, although some general increase of the efficiency of the inhibitory effect may be present as suggested by the slight influence on the pain threshold of teeth due to conditioning stimulation of hands.

Some further support for the hypothesis that low frequency conditioning stimulation interferes with the transmission of activity in the FRA system has been obtained in experiments in awake cats after conditioning with 2/sec. of forelimb and/or infraorbital nerves. The jaw opening reflex, considered analogous to the spinal flexion reflex (Sherrington, 1917), elicited by electrical stimulation of the tooth pulp was depressed in parallel with reduced aversive reactions (Andersson, 1973; Andersson, 1975). This observation is consistent with a short Chinese note indicating the

low frequency electro-acupuncture (1/sec.) simultaneously depresses the jaw opening reflex and reduces the cortical potential evoked by electrical stimulation of teeth (Peking Acupuncture Anaesthesia Co-ordinating Group 1973). Consistent results have also been obtained in experiments on cats where brain stem stimulation, previously known to induce analgesia, increased the threshold to jaw opening elicited by tooth pulp stimulation (Oliveras, Woda, Guilbaud and Besson, 1973).

Sjolund, B., Terenius, L., and Eriksson, M. Increased cerebrospinal fluid levels of endorphins after electro-acupuncture. *Acta Physiol. Scand.* 100, 382-384, 1977.

In modern Chinese acupuncture, low frequency electrical stimulation of the inserted needles is often used instead of the classical method of manual twirling (Kaada et al. 1974, Bonica 1974). As confirmed in Western investigations (Andersson et al. 1973, Chapman et al. 1975) the pain threshold of healthy volunteers is increased with the procedure. Moreover, electro-acupuncture performed via surface electrodes has been found to be more effective than that via needles (Andersson et al. 1973), probably because the amount of current passed can be larger and the seemingly necessary muscle twitches in adjacent regions therefore are stronger (Andersson et al. 1976b). Despite these results, attempts to use acupuncture for the long term relief of chronic pain have been largely unsuccessful (Andersson et al. 1976a, Gaw et al. 1975). However, by modifying the stimulation technique to reinforce muscle contractions, electro-acupuncture via surface electrodes can give satisfactory relief of chronic pain (Eriksson and Sjolund 1976).

The mechanism behind acupuncture analgesia remains unclear. However, naloxone, a specific opiate antagonist (Martin 1967), counteracts the increase in pain threshold in healthy individuals found after classical needle acupuncture (Mayer et al. 1975) as well as the analgesia from electro-acupuncture in patients with chronic pain (Sjolund and Eriksson 1976). A similar effect has recently been reported with mice receiving electro acupuncture (Pomeranz and Chiu 1976). These results suggest the activation of an inhibitory mechanism releasing endogenous morphinelike substances (endorphins; Hughes et al. 1975, Terenius and Wahlstrom 1975a). Since it is now possible to determine the concentrations of several endorphins in human cerebrospinal fluid (CSF; Terenius and Wahlstrom 1975b), we have investigated whether electro-acupuncture via surface electrodes (Eriksson and Sjolund 1976) changes the endorphin content of the CSF during the period of analgesia experienced by the patients.

The two chromatographic fractions (I and II) account for more than 75% of the total endorphin activity of the human CSF as measured in the receptor binding assay (Wahlstrom et al. 1976). In patients with no pain and apparently healthy, the CSF concentrations of these fractions, expressed as picomoles of Met-enkephalin/ml are 1.4±0.4 (mean ± S.E.) pmol/ml (I) and 5.2±1.8 pmol/ml (II) respectively (Terenius et al. 1976). From the present results it appears that the lumbar CSF content of fraction I is very low in all patients while experiencing pain, confirming earlier observations on patients with trigeminal neuralgia (Terenius and Wahlstrom 1975b). No systematic change is seen with fraction II. During stimulation analgesia a marked rise of endorphin fraction I in lumbar CSF is seen in patients no. 1-4, while this is not the case in the other patients.

Cheng, R.S., and Pomeranz, B.H. Electroacupuncture analgesia is mediated by stereospecific opiate receptors and is reversed by antagonists of type I receptors. *Life Sci.* Vol 26, pp. 631-638, 1980.

SUMMARY

Dextronaloxone, a recently synthesized stereoisomer, which was shown to possess much less opiate receptor affinity than levonaloxone, produces no reversal of electroacupuncture analgesia (EAA) in mice. Since levonaloxone completely reverses EAA, this proves that stereospecific opiate receptors are involved. It has been reported that there are two classes of opiate receptors: Type I and Type II. Type I opiate receptors may be responsible for opiate analgesia. Antagonists of Type I receptors, levonaloxone, naltrexone, cyclazocine and diprenorphine, all block electroacupuncture analgesia at low doses. All together, these results strongly support the hypothesis that electroacupuncture analgesia is mediated by opiate receptors. Possibly Type I receptors are the major components of this system.

Type I opiate receptors are found mostly in the brain areas which mediate analgesia (Pert, C.B., Taylor, D.P. and Pert, A 1979). They are most likely the receptors responsible for exogenous or endogenous opiate analgesia.

However, it is highly unlikely that Type II receptors are involved in EAA since Type I antagonists completely reverse EAA. These results (the stereo-specificity data, and the effects of Type I blockers) strongly support the hypothesis that opiate receptors are involved in electroacupuncture analgesia.

Reichmanis, M., and Becker, R.O. Relief of experimentally-induced pain by stimulation at acupuncture loci: a review. *Comparative Medicine East and West*. Vol V., No. 3-4 pp. 281-288, 1977.

24 recent studies on acupuncture analgesia for the relief of experimentally-induced pain are reviewed. Negative or equivocal results are reported in 7 of these. The remaining 17(71%) report significant analgesic effects during manual or electrical stimulation (particularly at very low frequencies on the order of 2 Hz) at acupuncture loci. Many investigators note that the full analgesic effect is attained only after about 20 minutes of stimulation. Further investigation of the analgesic effects of stimulation at acupuncture loci, particularly the effect of very low frequency electrical stimulation, is fully warranted by these preliminary findings.

Several studies have been conducted on the effects of stimulation at acupuncture loci for the relief of dental pain, notably by Andersson et al. In a preliminary report, they stated that electrical stimulation at point Li-4 (dorsum of the hand) and other points in the area of the infra-orbital nerve significantly increased pain thresholds in 30 subjects. The analgesic effect reached a maximum about 30 minutes upon cessation (Andersson et al 1973). Surface electrodes were more effective than subcutaneous electrodes, and low frequency constant current stimulation (2 Hz) was more effective than higher frequencies (10 Hz, 100 Hz) in inducing analgesia (Andersson, S.A., and Holmgren E. 1975). Omura (Omura, Y., 1975) has also noted that longer-lasting effects are obtained with very low frequency electrical stimulation. Further tests showed that a fairly strong stimulus was needed for any significant increase in pain threshold (Holmgren, E., 1975).

Andersson, S.A. Pain control by sensory stimulation. *Advances in Pain Research and Therapy*. Vol. 3 Ed. John J. Bonica et al, 1979.

TNS developed from the hypothesis of pain-controlling gates (Melzack, R., and Wall, P., 1965) according to which an increased activity in large afferent nerve fibers could produce pain relief by blocking of the transmission in the pain pathways.

In contrast to acupuncture, TNS is usually given at high frequency (50 to 100 Hz) and with low intensity which is kept well below that giving pain. The subjective sensation is different from that during acupuncture and is described as tingling or vibration. There are no phasic muscle movements, but a light tonic contraction may occur in muscles close to the stimulating electrodes. The afferent nerve fiber discharge consists of a continuous firing in low-end high-threshold afferents depending on the intensity.

FREQUENCY OF STIMULATION

Another relevant parameter of the sensory stimulation is its frequency. Pain threshold measurements have shown that low frequency (1 to 4 Hz) gives a gradual and slow increase of the threshold which remains elevated during a long-lasting stimulation and returns slowly in the poststimulation period. These effects contrast strongly the transient pain threshold observed during stimulation at high frequency (100 Hz). In spite of a continuous stimulation at high intensity, the pain threshold declines to the control level. It should also be noted that the effect is more localized than that at low frequency. Thus low-frequency stimulation of the cheeks increases the threshold of the teeth in both the upper and lower jaws, whereas high-frequency stimulation at the same location and intensity gives a transient effect only in the incisive and canine teeth of the upper jaw.

RELATION TO TRADITIONAL ACUPUNCTURE

Activation of high-threshold afferents is a common feature in needle manipulation and in electrical low-frequency stimulation. An obvious difference is, however, that needle stimulation has effects on receptors and afferents only in a limited region at the site of the needling whereas electrical stimulation must activate receptors in a much larger area in order to influence the pain.

Andersson et al. (Andersson, S.A., Block, F., and Holmgren E., 1976) tested low-frequency stimulation applied via surface electrodes. Stimulation at 2 Hz and with an intensity which elicited strong muscle contractions was given at the low back region bilaterally. The pain relief was very good or good in 48% of the women and some analgesia occurred in 37%. The results suggested a relation between high suggestibility and good analgesic effect. However, the study did not indicate that the pain relief was due to the suggestibility only since both suggestion and hypnosis had been used prior to the sensory stimulation without producing pain relief. Probably there are some factors which predispose for both hypnosibility and analgesic effect during sensory stimulation.

When the low-frequency, high-intensity stimulation is modified into repetitive, high-frequency bursts, the conditioning is less distressing and pain conditions not relieved by high-frequency stimulation can be alleviated (Eriksson, M. and Sjolund, B. 1976).

There is evidence that low-frequency stimulation (acupuncture) activates descending control systems. Naloxone decreases or (?) eliminates the analgesia produced by classic needle acupuncture in healthy subjects. (Mayer, J.D., Price, E.R., Rafii, A., 1975). Moreover, naloxone inhibits the pain relief elicited by low- frequency electrical stimulation in patients with chronic pain but it does not counteract analgesic effects produced by high-frequency sensory stimulation (Sjolund, B., and Eriksson, M.,1977). A low concentration of endorphins is often found in the cerebrospinal fluid (CSF) of patients with chronic pain of somatic origin as compared to pain of psychogenic origin (Almay, B.G. et al., 1978). Low frequency electrical stimulation producing pain relief increases the CSF concentration of endorphins (Sjolund, B., Terenius, L., and Eriksson, M. 1977). The counteraction by naloxone of the pain relief after acupuncture could thus be due to an effect on the endorphin release by the stimulation.

Mannheimer, J.S., and Lampe, G.N. Clinical transcutaneous electrical nerve stimulation. Philadelphia: FA. Davis, p. 341, 1984.

STRONG, LOW -RATE (ACUPUNCTURE - LIKE) T.E.N.S.

Electrical parameters adjusted to provide a low rate 1 to 4 Hz), wide pulse width (150 to 250 usec), and high intensity are know as strong, low-rate (acupuncture-like) T.E.N.S. To be effective, this mode of T.E.N.S. requires an induction period of at least 20 to 30 minutes and must produce strong, visible muscle contractions in segmentally related myotomes. In those experiments comparing the effects of needle or surface stimulation (percutaneous versus transcutaneous), similar results were obtained and in many cases they were somewhat better with surface stimulation.

This mode of stimulation provides a definite prolonged aftereffect of pain relief, which seems to be related to the long onset.

Hansson, P., and Ekblom, A. Transcutaneous electrical nerve stimulation (TENS) as compared to placebo TENS for the relief of acute oro-facial pain. Pain. Vol 15, pp. 157-165, 1983.

SUMMARY

The present paper describes the effect of high frequency, low frequency and placebo TENS on acute oro-facial pain in 62 patients, attending to an emergency clinic for dental surgery; they had all suffered pain for 1-4 days. The patients were randomly assigned to one of three groups receiving either high frequency (100 Hz), low frequency (2 Hz) or placebo TENS. In the two groups receiving TENS (42 patients) 16 patients reported a reduction in pain intensity exceeding 50%; out of these 16 patients, 4 patients reported complete relief of pain. In the placebo group (20 patients) 2 patients reported a pain reduction of more than 50%; out of these 2 patients, none reported a complete pain relief

METHODS

The effect of TENS and placebo TENS was studied in 62 patients aged 19- 54 years (26 males and 36 females) admitted to an emergency clinic for dental surgery for treatment of oro-facial pain. The most common causes for the pain were pulpal inflammation, apical periodontitis (including facial abscesses) and postoperative pain following removal of a tooth. Patients with these diagnoses were represented in equal numbers in the test groups and in the placebo group. All patients suffered from acute pain; most of the patients had experienced pain for 1- 4 days. None of them had taken analgesics within 6 h before submitted for treatment. All of the patients were examined, told the diagnosis and asked if they would take part in the experiments. Those willing to participate were informed about their role in the experiment. Furthermore the subjects were told that they might or might not experience pain relief as well as aggravation of pain during stimulation. Every effort was made to avoid suggestion. The patients were told that they could stop the stimulation at any time and all the patients were informed that they would get a conventional dental treatment after termination of the stimulation.

The patients were assigned randomly to one of the three groups, high frequency, low frequency or placebo TENS. They were asked to rate their pain intensity before they received any stimulation, by using a 5-graded verbal scale.

DISCUSSION

Previous studies concerning the pain reducing effect of TENS in acute (Augustinsson, et al 1977, Hymes, et al 1974, Rosenberg, et al, 1978, and Van der Ark, et al 1975) and chronic (Ihalainen, et al 1978, Loeser, et al 1975, Long, et al 1975, and Picaza, et al 1975) pain of different origin are consistent in showing temporary alleviation of pain in about 50% of the patients. It must be pointed out, however, that different authors use different criteria in evaluating the pain reduction obtained by TENS, which makes it difficult to compare results in various reports.

The findings in the present study clearly show that TENS of either 100 or 2 Hz may reduce or abolish acute oro-facial pain. On the basis of our results, no significant difference could be observed between the pain relieving effect of high frequency and low frequency TENS. However, it should be noted that most patients found the muscle twitches produced by the low frequency TENS uncomfortable. This was in contrast to high frequency TENS which most often produced a pleasant sensation and a feeling of warmth. Sixteen of the 42 patients treated with TENS experienced a pain relief exceeding 50%, which in the placebo group 2 out of 20 patients reported a similar degree of decrease in pain intensity. The magnitude of the placebo effect in this study, if considering all patients in the placebo group who reported some relief of pain (i.e., 8 out of 20 patients), is similar to that reported in other studies (Thorsteinsson, et al 1978), i.e., a 40% placebo effect. The difference between the pain alleviating effect of TENS as compared to placebo TENS suggests that the reduction of pain obtained in the present study is unlikely to be due to placebo effects.

In studies of any method of treating pain it is important to compare the pain alleviation obtained with that of other modes of treatment. We did compare TENS and placebo TENS to the pain relief obtained from pharmacological substances used by the patients before visiting the clinic. It is interesting to note that only 1 of the 5 patients receiving placebo TENS rated this superior to the analgesic medication used, while 12 out of 23 patients receiving TENS rated the TENS effect higher than analgesics used. All patients rating TENS and placebo - TENS superior to the specific analgesic medication used, experienced a pain relief from TENS or from placebo-TENS exceeding 50%

In conclusion, the observations in the present study suggest that acute oro - facial pain can be effectively reduced by TENS, either at 100 or at 2 Hz. The results of the present study and previous findings (Ottoson, et al 1981) further suggest that vibratory stimulation in some cases is superior to TENS.

Terezhalmay, G.T., Ross, G.R. and Holmes-Johnson, E. Transcutaneous electrical nerve stimulation treatment of TMJ-MPDS patients. *Ear, Nose and Throat Journal*. Vol 61, pp. 22-28, December 1982.

Correct diagnosis and selection of the most effective therapeutic approach for the management of TMJ - MPDS require not only knowledge of the etiology, physiopathology, symptomatology, and affective qualities of the pain syndrome but also an awareness of the availability of different modes of therapy. The purpose of this study is to examine the effect of transcutaneous electrical nerve stimulation (TENS) on patients with TMJ-MPDS and to analyze factors that might influence patient response to transcutaneous stimulation.

TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION

The Panel on Review of Neurological Devices of the Food and Drug Administration concluded in its 1976 report that (1) TENS is progressing in technical sophistication, (2) a reasonable and acceptable degree of efficacy has been documented in long-term trials, (3) TENS is being accepted by many members of the health care community as a safe and simple therapeutic means of alleviating pain, and (4) TENS provides a meaningful alternative to other types of pain therapy that are known to have a higher degree of risk (FDA Report, 1976)

MATERIALS AND METHODS

Twenty-five patients suffering from pain associated with TMJ-MPDS participated in this study. These patients were selected on the basis of one or more of the following criteria: (1) intrajoint pain associated with muscle tenderness and ear symptoms; (2) muscle spasms related to fatigue and tension due to sudden or chronic stretch; (3) a combination of intrajoint pain and muscle spasms; (4) referred pain from trigger points within a muscle in spasm, and (5) limitation or loss of mandibular function without evidence of systemic or neoplastic disease. Informed consent was obtained from all patients.

A Pain Rating Index was developed on the basis of the McGill Pain Questionnaire's intensity scale in the sensory temporal, constrictive pressure, dullness, and miscellaneous categories; evaluative category; and two supplementary miscellaneous subclasses. Each subclass has an intensity scale ranging from 1 to 5 in order of increasing intensity. The intensity scores in each subclass were added to determine the Pain Rating Index for each patient

DISCUSSION

Our study indicates that TENS offers a rapid, noninvasive, and generally predictable means of pain suppression. It can be a valuable alternative to other modes of therapy in the treatment of TMJ-MPDS. If TENS therapy is successful, no other treatment would appear to be necessary. When TENS therapy is less than effective or does not give the desired pain relief, other treatment modalities must be considered. Correction of minor and major dental occlusal discrepancies, pharmacotherapy, and surgery are invasive procedures and are therefore not without risk. As such, we believe that biofeedback techniques and psychological counseling may appropriately take precedence in the treatment of the patient with TMJ - MPDS.

Although comparisons of TENS treatment with a placebo were not done in this study, two separate investigators have shown that the placebo effect with TENS is in the range of 32 to 33 percent (Loeser, et al 1975, Thorsteinsson, et al, 1977). In both of these studies, the placebo effect appeared to be brief and gave little evidence to support the contention that the effect persists for any significant period of time. Our findings of 72 percent long-term responses were considerably greater than the accepted placebo effect.

The McGill Pain Questionnaire appeared to be sufficiently sensitive to provide the clinician with important information concerning patient response to TENS. It has the potential for providing qualitative and quantitative data that can be analyzed, and it should be useful in distinguishing among the effects of different methods of controlling pain

CONCLUSION

TENS is an effective, noninvasive means for suppressing pain caused by TMJ-MPDS. Patient responses to treatment may be evaluated with the McGill Pain Questionnaire. The MMPI provides important information concerning the patient's emotional equilibrium and is a valuable prognostic tool. Our data suggests that TMJ-MPDS is multifactorial and that no single discipline or therapeutic approach should necessarily be considered the only method for patient management.

Phero, J.C., Raj, P. P., and McDonald, J.S. Transcutaneous electrical nerve stimulation and myoneural injection therapy for management of chronic myofascial pain. *The Dental Clinics of North America*. Vol. 31, No. 4, October 1987.

TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION

The present-day use of TENS began after the 1965 publication of Melzack and Wall's classic paper "Pain Mechanisms: A New Theory" (Melzack, et al 1965). Two years later, it was found that external application of electrical stimulation was effective in relieving pain. This technique was used to determine if a patient was a suitable candidate for the surgical implantation of dorsal column electrodes (Shealy, C. 1972). These researchers laid the foundation for the current utilization of TENS to manage acute and chronic pain.

TENS has been used in a variety of health care settings including pain control centers, emergency rooms, operating rooms, postanesthesia care units, and labor rooms. There is a need for health professionals to develop knowledge and expertise in this noninvasive method of providing patient analgesia. Of key importance is the area of patient education in the use of TENS. With proper training and equipment, the patient can learn to utilize a TENS unit at home with satisfactory results often giving them a significant degree of self-control over their chronic pain.

THEORIES ON MECHANISM OF ACTION

The placebo effect noted with the use of TENS has been a subject of study by many researchers. The placebo effect is believed to be minimal (Long, D. 1974). If it occurs during a trial of TENS it will not be sustained.

INDICATIONS FOR TENS

TENS has been demonstrated to be effective in relieving both acute and chronic pain. TENS therapy alone may be sufficient to modulate pain, but it is most often used in conjunction with other modalities of therapy to maintain relaxation and relief of pain

GOALS OF TENS THERAPY

The goals of TENS therapy as a single modality or in conjunction with other modalities are as follows: a 50 per cent decrease in pain, a 50 per cent increase in function and mobility, and a 50 per cent decrease in medication with the elimination of agents with addictive potential. These results have been obtained using TENS on patients experiencing acute pain and chronic pain (Hymes, et al 1974, Long, D. 1977, Shealy, C. 1972, Shealy, C.N. 1974)

MODES OF STIMULATION

ACUPUNCTURE MODE (HIGH WIDTH, LOW RATE)

This setting is often the second mode of choice and is very effective for deep, aching chronic pain. It is useful when previous nerve damage has occurred (3M: TENS, 1983). This mode stimulates the cutaneous, subcutaneous and deep nerve fibers. A low rate, <10 pps, usually 2 to 4 pps, is used along with a high width. The amplitude is adjusted to the point at which muscle contraction is seen. Studies have shown that acupuncture-like TENS activates the production of endorphins (Sjolund, et al 1979)

SUMMARY

Over the last several years TENS therapy has become extremely popular to a large extent because it is a noninvasive technique that most patients can be taught to use safely and effectively. An additional advantage to TENS therapy is that it provides many patients with some means of control over their pain, independent of medications and hands-on therapy by health care providers

MYO-MONITOR NEURAL MEDIATION VS. MUSCLE STIMULATION

INTRODUCTION

The following articles are controlled studies supporting the thesis that Myo - monitor induced contraction of muscles is neurally mediated.

Jankelson, B., Spark, S. and Crane, P. Neural conduction of the Myo-monitor stimulus: A quantitative analysis. J. Prosthetic Dentistry. Vol 34 No. 3, pp 245- 253 September 1975.

PURPOSE AND SCOPE OF THE INVESTIGATION

The purpose of this investigation was to examine the response of muscles to external stimulation in order to determine whether the resulting contraction was mediated by direct depolarization of the muscle membrane or whether it resulted from an induced neural action potential which stimulated the muscle via the neuromuscular junction. The scope of this investigation was limited to the specific question of whether contractions that follow transcutaneous stimulation with the Myo-Monitor result from direct muscle fiber stimulation (De Boever, J., and McCall W.D. 1972; Bessette, R.W. and Quinlivan J.T. 1973) or whether the contractions are a response to stimuli transmitted through the motor nerves (Choi, B., and Mitani H., 1973).

METHOD OF INTENSITY-DURATION CURVES

Intensity-duration testing was selected as the core method for the experiments, because it is well established and reliable: “. . . the technique that has proved most satisfactory and is in widest use is the recording of the intensity-duration relationship of applied electrical stimuli. It is a straightforward and reliable investigation. The relationship between the strength of the stimulus and its duration in time for a constant response of an excitable tissue gives an accurate measure of the excitability of that tissue.” (Lenman, J., and Ritchie, A.E. 1973).

This method is based on the observation made in 1883 by Erb (Erb, W. 1883) that has since been firmly established. That is, a long-lasting stimulus will excite both nerve and muscle, whereas a short stimulus will excite only the nerve. Hence, if a stimulus, known to be too short in duration to directly cause muscle depolarization, is applied and muscle contraction results, it can be confidently concluded that the stimulus responsible for the contraction arrived via the motor nerve.

DESCRIPTION OF THE EXPERIMENT

Subjects: The subject sample consisted of six women and four men, ranging from 20 to 60 years of age. One of the subjects was completely edentulous, and none reported clinical symptoms of T.M.J. disorders, occlusal problems, or serious muscle spasm.

Recording curves: The technique of intensity-duration recording requires that one detect the occurrence of a consistent minimal response. While detection of threshold contraction by careful palpation and inspection has been considered adequate and is the means most commonly used in intensity-duration testing, a graphic form of recording has long been sought to lend further objectivity and accuracy to the method.(Lenman, J., and Ritchie A.E., 1973) In these experiments, the mandibular kinesiograph, (Jankelson, B. et al., 1975) an instrument which electronically senses and records mandibular movement, was used to precisely measure and record a consistent amount of mandibular rise (closure). Since the amount of mandibular closure is directly correlated to the degree of muscle contraction, precise graphic recording of the amount of closure assured that a consistent contraction was elicited for each of the various stimulus duration. Throughout the investigation, for each subject and at each stimulus duration being used, the intensity of the stimulus was monitored and adjusted to produce the uniform. 0.2 mm. mandibular closure. Kinesiometric recording of consistent contraction proved to be a useful refinement in intensity-duration testing.

INVESTIGATION TO PROVE APPLICABILITY OF MYO-MONITOR

Following the same protocol as outlined earlier, a subject was sequentially stimulated through the same electrodes with a constant-voltage source, the MyoMonitor, and a constant-current source. In this manner, comparative peak currents could be measured without disturbing the electrode positions, thereby making it possible to assess the relative effect of the Myo-Monitor pulse. The peak current was adjusted for each subject to produce a consistent 0.2 mm. mandibular closure.

A mathematical routine employing a least-squares curve-fitting program was used to match the standard intensity-duration curve to the data. As was done earlier, the data was expressed as a ratio relative to the peak current at 3 msec.

Further examination of the data leads to the conclusion that Myo-Monitor is indeed adequate for use in our investigation. Also, because even the constant current stimulator did not result in a chronaxy of greater than 0.26 msec., these data alone are strong evidence for neural mediation of the current stimulus.

RESULTS

Data on current recordings. Peak current records from the 10 subjects are presented in Table 1. The spread in peak current values for any given pulse duration reflects the variability in anatomic configuration that is to be expected in a population. Fig. 4 expresses these data in terms of the relative stimulus intensity, which is defined as the ratio of the peak current required at a duration of 3.0 msec. (rheobase). Data displayed in this manner tend to normalize the anatomic variability without distorting the critical parameters of the experiment. The mean ratio of the population is plotted in Fig.4.

Chronaxy. The use of transcutaneous stimulation as a diagnostic aid in the determination of muscular innervation hinges on the clear-cut distinction between the excitability curves for nerve and muscle. Among the indices used to quantify intensity-duration curves is the chronaxy, which is defined as the time required for a stimulus of twice the threshold intensity (rheobase) to elicit a consistent response. A mathematical analysis (formula follows) of the data shown in Fig. 4 yields a chronaxy of approximately 0.158 msec. at a relative stimulus intensity of 2.0. Individual chronaxies for the 10 subjects ranged from 0.125 to 0.180 msec. Myo-monitor - Neural Mediation

In all 10 subjects, individual curves followed the same general hyperbolic shape with no significant discontinuities. The data were fitted with a curve of the form:

$$I = I_0 \frac{1}{1 - e^{-t/k}}$$

where: I = stimulation current (Ma.); I₀ = rheobase current (Ma.); t = duration of current pulse (msec.); and k = characteristic of data (time constant, msec.).

Chronaxy values for normal muscles of the face being stimulated through their motor nerve range from 0.02 to 0.3 msec., depending primarily on the stimulator impedance. If the muscle fibers were being stimulated directly, without the transmission of the signal across the neuromuscular junction, the chronaxy value would be from 50 to 100 times greater (Fig. 5). (Watkins, A.L. 1968; Harris, R., 1971)

DISCUSSION

The intensity-duration curves reported for this study support the findings of a previous electromyographic study (Choi, B.B., and Mitani, H., 1973), that is, the muscle contraction resulting from Myo-Monitor stimulation is generated through a neurally mediated sequence. In that investigation of 15 subjects in which tiny wire electrodes were used, it was reported that, "The evoked E.M.G. was recorded from anterior portion of the temporal, the masseter, anterior ventral of the digastric, the obicularis oris and the buccinator muscles....The Myo-monitor pulse stimulates the nerve trunks of the fifth and seventh cranial nerves at the superior mandibular notch percutaneously and it appeared to have afferent and efferent effects. (Choi, B.B., and Mitani, H., 1973).

However, Bessette and Quinlivan, (Bessette, R.W. and Quinlivan, J.T., 1973) in another electromyographic study using surface electrodes, reported that they were unable to record a consistent response from the anterior temporal muscle in five subjects, and in one of the five subjects, a wire electrode inserted into the medial pterygoid muscle failed to detect myographic evidence of contraction. These investigators also measured a single latency and used that measurement to calculate what they incorrectly defined as "conduction velocity." From that calculation and their inability to record electromyographic signals from the temporal or the medial pterygoid muscles, they concluded that neural conduction was not involved and the contraction was the result of direct stimulation of only the masseter muscle fibers.

When confronted with differing conclusions, one must look to the conditions of the experiment and the analysis of the data.

In the study by Bessette and Quinlivan (Bessette, R.W. and Quinlivan, J.T., 1973) which concluded that neural conduction was not involved, in all five subjects, the single latency was measured as the time from start of the stimulus to peak of the response. This departure from the conventional definition of latency (the time from start of the stimulus to the onset of response) produced a measurement of 3 msec., which then became the basis for their, “conduction-velocity” calculations.

To obtain accurate conduction-velocity measurements, stimulation must be done at two points along the nerve and the latency measured for each response. The distance between the two points of stimulation must then be divided by the difference between the two measurements of latency so that, in calculating the velocity, and allowance is made for the time it takes the impulse to cross the neuromuscular junction, (Watkins, A.L., 1968; Lenman, J., and Ritchie, A.E., 1973; Goodgold, J., and Eberstein, A., 1972; Johnson, E.W., 1971)

$$\text{Conduction velocity} = \frac{\text{Distance}}{(\text{Latency 2} - \text{Latency 1})}$$

A single latency, as used by Bessette and Quinlivan, (Bessette, R.W. and Quinlivan, J.T., 1973) does not give a true indication of conduction velocity along the nerve.

In contrast with peak measurement, the conventional measurement to onset of response would yield a latency of 2 msec. or less (See Bessette and Quinlivan, (Bessette, R.W. and Quinlivan, J.T., 1973) Fig. 2). The neurally mediated pathway would incur (1) a finite delay in charging dermal capacity of about 0.5 msec., (2) neural conduction time (assuming a conduction velocity of 69 M. per second over a distance of cm.) of 0.46 msec., (3) a delay of 0.3 to 1 msec. at the neuromuscular junction, and (4) an intermuscular delay dependent on electrode placement. A latency of 2 msec. (Oester, Y.T. and Light, S., 1971) is well within the expected range of a neurally mediated response.

Neither the methodology nor the analysis of the data of the investigation under discussion (Bessette, R.W. and Quinlivan, J.T., 1973) provided for recognition of neural stimulation that might have occurred. The conclusions that the nerve trunk is anatomically inaccessible to a stimulus and that only muscle fiber stimulation was involved are not warranted either by the method of the data analysis of the experiment.

SUMMARY

With the introduction of the Myo-Monitor to dentistry, the question has arisen whether the stimulus is neurally mediated (Choi, B.B. and Mitani, H., 1973) or results from direct depolarization of only the fibers of the masseter muscle. (Bessette, R.W. and Quinlivan, J.T., 1973) Intensity-duration curves recorded for 10 subjects quantified the relationship between stimulus intensity and the duration of the stimulus required to elicit a consistent contraction response to transcutaneous stimulation via the Myo-Monitor. Individual chronaxies ranged from 0.125 to 0.180 msec., with a mean calculated at 0.158 msec. Stimulating the muscle fibers directly, without transmission of the signal across the neuromuscular junction, would have produced chronaxy values a least 50 to 100 times greater. The distinction is clear-cut. The chronaxy values unequivocally establish transmission of the stimulus across the neuromuscular junction.

In all 10 subjects, contraction of muscles remote from the site of stimulation was evident by inspection and palpation. These data lend support to the conclusion of Choi and Mitani (Choi, B.B. and Mitani, H., 1973) that the MyoMonitor stimulates the fifth and seventh cranial nerves.

The data derived here correlate with those of other investigations and clearly establish that the transmission of the Myo-monitor stimulus is accomplished by transcutaneous neural stimulation.

Fujii, H. Evoked EMG of masseter and temporalis muscles in man. J. of Oral Rehabilitation. Vol 4, pp 291-303, 1977.

SUMMARY

Following a percutaneous stimulation on the mandibular notch skin, two kinds of responses were recorded in the ipsilateral masseter and temporal muscles in man. The two responses had their proper stimulating points. The early response appeared with about 2 ms latency and the late one with about a 6 ms latency which was shorter than that of T wave of the same muscle by about 1 ms. No responses were induced in the contralateral masseter and temporal muscles.

Regarding the recovery process of the late response following double stimuli, a testing late response was released about 100% from the effect of conditioning shock at a longer interval than 80-95 ms. It might be safe to consider that the previous assumption, i.e. those two responses seemed to be M and H waves respectively, had been fortified. H response evoked in muscles tested seems to be sensitive enough to show the difference between excitatory states of its reflex arc.

EFFECTS OF STIMULUS ON CONTRALATERAL MUSCLES

After the upper mandibular notch skin was unilaterally stimulated, the EMG of the contralateral masseter, the anterior and posterior portions of the temporal muscles were picked up. In the contralateral muscles, however, it was impossible to record obvious responses (Fig. 5-bd) which were detected in the ipsilateral muscle (Fig. 5-a.), but with about a 10 ms latency a silent period appeared.

LATENCY OF A LATE RESPONSE

A late response and jaw-jerk (zygomatic reflex) response which is known as monosynaptic were recorded under the same condition in order to make a comparison. One example is shown in Fig. 6; fifteen late responses from each muscle tested of the same subject are shown in Table 1 in comparison with the latency of T wave (Paillard, 1955). The average latencies of late responses from the masseter and the anterior and posterior portions of the temporal muscles were 5.97 ± 0.059 ms, 6.06 ± 0.152 ms, and 6.28 ± 0.117 ms respectively, the corresponding average latencies of T wave being 6.78 ± 0.136 ms, 6.89 ± 0.249 ms, and 6.98 ± 0.084 ms. A significant difference was observed between the latency of a late response and the latency of T wave in each muscle ($p < 0.001$).

DETECTION RATE AND TYPE OF A LATE RESPONSE

From the above results, the early and late responses obtained were likely to be M wave and H wave respectively, in order to clarify the qualities of these responses, a study was carried out on the detection rate and type of the responses picked up from the masseter and temporal muscles.

As a result, it was understood that in the masseter and temporal muscles, the detection rate of H wave was lowered and the threshold of the H wave was mostly higher than that of M wave (high type) under resting conditions. However the H wave was easily detectable and the threshold of H wave mostly lower than that of M wave (low type) under a voluntary contraction.

DISCUSSION

ELECTRIC STIMULATION

When an attempt is made to induce H wave by stimulating the nerve fibres innervating the muscle percutaneously, the site where the nerve trunk is adjacent to the skin is generally adopted as a stimulating point. The masseter and temporal muscles are innervated with the masseteric nerve and the deep temporal nerve which are branches of the trigeminal nerve. Both nerve trunks are situated uppermost under the mandibular notch skin and under the anteroinferior wall of the external acoustic meatus (Shapiro, 1954; Ota, 1974). Accordingly, the mandibular notch area seems to be the most favorable position to stimulate the nerve trunks of the masseteric nerve and the deep temporal nerve percutaneously.

Even if the indifferent electrode is removed from the face surface to the brachial area there are induced two responses (Fig. 4), while when the indifferent electrode is moved 15mm from the most effective portion the above responses can be no longer recorded (Fig. 3). This obviously shows that the responses actually recorded resulted from the stimulating effects of the indifferent electrode.

EARLY RESPONSE

Two possibilities are considered regarding the character of the early response recorded in the current experiments; one, M wave due to stimulation of the motor fibres and the other the direct response due to stimulation of muscle fibres. It is reported that the conduction velocity of an action potential in the muscle fibre is about 35 m/s at 37°C (Buchthal, Guld & Rosenfalck, 1955; Stalberg, 1966; Ganong, 1971), which reaches 4.7 +/- 1.3 m/s at a voluntary contraction (Midi & Tokizane, 1967). Presently the shortest distance between the stimulating point and the leading electrode is about 4 cm in the masseter muscle and 78 cm in the temporal muscle. Thus, supposing an action potential produced by excitation on the muscle fibres at the stimulating point reaches the recording point with a conduction through these fibres, latency would be 6.67 ms for the masseter muscle and 11.67 ms for the anterior and posterior portions of the temporal muscles. But the latency of an early response which is actually induced from the masseter and the anterior and posterior portions of the temporal muscles was about 2 ms. If it is assumed that the fibres of the masseteric and deep temporal nerves are 12 μ m(?) in diameter (Carlsoo, 1958), their conduction velocity is about 69 m/s (Gasser & Grundfest, 1939) and an action potential in motor fibres produced by electric shock is conducted through most of the distance between the stimulating point and leading electrode along the motor fibres, the time required for conduction is 0.58 ms for the masseter muscle and 1.01 ms for the temporal muscle. When these values are added with an end plate delay value which was assumed as 0.31.0 ms (Eccles & O'Connor, 1939; Katz & Miledi, 1965; Enomoto et al., 1968) and some intermuscular delay value (McIntyre & Robinson, 1959), about 2 ms is obtained which gives good correspondence with the latency of an early response. Accordingly, this would suggest that an early response is of M wave character. The present result that an early response has a special stimulating point (Figs 3 & 4) strongly supports this likelihood.

LATE RESPONSE

Changes in the amplitude of a late response subsequent to an increase of stimulus show a pattern, similar to those of the H wave of the extremity muscles. Furthermore, it has been reported that the late response was free from any effects of superficial sensations around the stimulating electrode (Fujii & Mitani, 1973).

The latency of the jaw jerk known as a stretch reflex of the jaw closing muscles has ranged widely from 6.5 to 9.9 ms, depending upon individual authors (Kugelberg, 1952; McIntyre & Robinson, 1959; Goodwill, 1968; Goldberg, 1971; Munro & Griffin, 1971; Hannam, 1972). This suggests that the latency may be subject to the initial condition of the muscle and to the method of stimulation. Therefore in the current experiments a jaw jerk (Zygomatic reflex) was elicited under the same condition as a late response and recorded as T wave, in an attempt to make a comparison with the latency of a late response. The result showed a T wave with a slightly longer latency than the corresponding late response (Table 1). The T wave is a response elicited through the simplest reflex arc, and since a late response here obtained had a shorter latency than that of T wave, there seem to be two possibilities as to the nature of a late response; on F wave and the other H wave. It is said that the F wave has a higher threshold than the M wave and can be induced by supramaximal stimulus on the M wave, and that it shows a high amplitude during high excitability of the motoneuron and can be recorded from small muscles in the extremities and the Face (Dawson & Merton, 1956; Mayer & Feldman, 1967; Fra & Brignolio, 1968). However, a late response, when viewed from the recovery process of the testing late response, can not be considered to be an F wave (Mayer & Feldman, 1967) which is free from an inhibitory effect of conditioning shock at 220 ms intervals. It shows a recovery process which is similar to that found in the recovery curve of H wave (Tei, 1961) any conditioning shock effect at 8090 ms intervals (Fig. 7, left), being possessed of features of monosynaptic response. Therefore, this late response is assumed to be an H wave and its reflex arc to be composed of the neurons of the mesencephalic and motor nuclei of the trigeminal nerve.

LATENCY OF H WAVE

McIntyre & Robinson (1959) report that the human masseteric nerve is 1012.5 cm long; Munro & Griffin (1971) describe the human masseteric nerve and deep temporal nerve as about 8.1 cm and 7.6 cm long, respectively. The present author has measured the length between the peripheral end of either the masseteric nerve or the deep temporal nerve and the mesencephalic nucleus of the Vth cranial nerve to be 11 cm in a Japanese cadaver.

As mentioned above, if the conduction velocity of the above nerve fibres is assumed to be about 69 m/s, both afferent and efferent conduction times will be about 1.6 ms. In the present study the latency of a late response was obtained as about 6.0 ms. On an assumption that a synaptic delay (Harrison & Corbin 1942; Enomoto et al., 1968) and an end plate delay (Eccles & O'Connor, 1939) are about 1.0 ms and 0.7 ms respectively, the remaining 1.0 ms or so would agree with an intermuscular delay (McIntyre & Robinson, 1959). Therefore, it seems safe to consider that the difference in latency with the T wave represents a receptor delay.

Fujii, H., and Mitani, H. Reflex responses of the masseter and temporal muscles in man. J. of Dental Research. Vol 52, No. 5, pp 1046-1050, 1973.

The H Wave represents a monosynaptic reflex potential of the skeletal muscle that is evoked after selective electric stimulation of the G I a fibers.

COMPARISONS OF LATENCY BETWEEN T WAVE AND A LATE RESPONSE

The latencies of a T wave and late response recorded from the anterior portion of the temporal muscle were about 7.0 and 6.0 msec, respectively (Fig. 4). These latencies were almost the same in the masseter and posterior temporal muscles. Thus, the T wave in all muscles always showed a slightly longer latency.

THE RECOVER CURVE

Double stimuli were given at an intensity at which a control late response showed its highest amplitude (Fig. 5a), and they were subjected to changing intervals. Our results showed 0% amplitude at intervals of less than 10 msec (Fig. 5b), 28% at 20 msec (Fig.5c), 115% at 45 msec (Fig. 5e), and 109% at 60 msec (Fig. 5f), in the masseter muscle.

A recovery curve is shown at the bottom of Figure 5. The anterior and posterior portions of the temporal muscle during medium jaw clenching showed a recovery process similar to that of the masseter muscle.

DISCUSSION

Investigations (Harrison & Corbin, 1942; Szentagothai, 1948; McIntyre, 1951; Astrom, 1953; Jerge, 1963; Kawamura, 1964) have indicated that the jaw-closing muscles of some animals are governed by monosynaptic innervation, which is the case with upper and lower limbs. At present, few investigators deny that the jaw-closing muscles in man are controlled by proprioceptive innervation monosynaptically. (McIntyre & Robinson, 1959)

Hugelin and Bonvallet, Enomoto et al, and Kawamura, Takata, and Miyoshi recorded action potentials from the masseteric nerve in animals after electric stimulation of the trigeminal mesencephalic tract (nucleus). An impulse resulting from the stimulation was conducted along the G I a fibers antidromically; another impulse descended along the motor fibers by way of a single synapse. The impulses were recorded as a direct response and a monosynaptic reflex response, respectively, in the distal site of the masseteric nerve.

Furthermore, Nakamura, Goldberg and Clemente recorded monosynaptic reflex discharge from the masseteric nerve in a cat after stimulation of the same nerve at a location more proximal than the recording electrode.

Presently, an early response from the masseter and temporal muscles seems to be identified with an M wave (base on latency and response to a gradual increase of stimulus intensity). The M wave represents a direct muscular excitation that originates from the motor nerve stimulation.

A late response, which appears mainly during jaw clenching, is considered to be different in nature from an M wave (based on its response toward a gradual increase of stimulus intensity and double stimuli). The finding that this response did not disappear even while superficial sensation around the stimulated areas was blocked indicated that the response was not a superficial reflex. It also was demonstrated that the T wave always had a longer latency, by 0.5 to 1.0 msec. than a late response. This difference may be considered to be a receptor delay. (McIntyre & Robinson, 1959)

We found that the recovery curve obtained was shifted more to the left than the recovery curve (Magladery, 1955) of the H wave obtained from some lower limb skeletal, muscles of normal individuals, the latter finding seems to be related to a rise in the excitatory state of the motoneuron pool because of a sustained voluntary contraction.

Thus, a late response seems to be reflex in nature, that is an H wave. Impulses evoked by an electric stimulation of the G I a fibers, which supply the related muscle, are transmitted to the trigeminal motor nucleus monosynaptically from the trigeminal mesencephalic nucleus; this results in the development of a reflex response (H wave).

The data in Figure 2 indicate that afferent fibers have a threshold that is lower than or equal to that of efferent fibers. Accordingly at the level of intensity at which efferent fibers are stimulated, afferent fibers already have been stimulate; some impulses developed in efferent fibers ascend antidromically and abolish orthodromic impulses by way of G I a fibers.

Homma reported that the H wave is recorded easily during voluntary contraction, because the motoneurons already have been stimulated as a result of descending impulses from the upper center. This results in the abolishment of antidromic impulses and leads to an increase of the subliminal fringe in the motoneuron pool and facilitation of the reflex arc. His findings are supported by the present experimental data.

Based on the assumption that the distance from the stimulating site to the center of the nerve was about 11 cm, and that the conducting velocity of the nerve was 69 meters/second, the latency of a late response may be estimated as follows: Afferent and efferent conduction times are each about 1.6 msec; the synaptic delay at the center is about 1.0 msec; the effector delay is about 0.7 msec; the intermuscular delay is about 1.0 msec, which is the remaining period.

CONCLUSIONS

After percutaneous electric stimulation of the masseteric and deep temporal nerves, the eletromyographic response of the masseter muscle and of the anterior and posterior portions of the temporal muscle was determined.

Two kinds of response were obtained with latencies of about 2.0 msec. and about 6.0 msec. respectively. The former was assumed to be a direct potential (M wave) and the latter a monosynaptic reflex potential (H wave).

Choi, B. On the mandibular position regulated by Myomonitor stimulation. J. Japanese Prosthetic Dentistry. Vol. 17, pp 73-96, 1973.

In order to clarify the stimulating characteristics and their effects of a Myo-monitor and to investigate the mandibular position, 10 normal and 5 edentulous subjects without stomatognathic symptoms were studied. After examination of the direct output pulse and percutaneous pulse, the Myo-monitor was used according to the instruction manual. The evoke EMG was recorded from anterior portion of the temporal, the masseter, anterior venter of the digastric, the orbicularis oris and the buccinator muscles. Mandibular movement was recorded with pin-pointed miniature lamp luminograph in three dimensions.

Following the investigation of evoked EMG, it was clarified that the Myomonitor pulse stimulates the nerve trunks of the Vth and VIIIth cranial nerves at the superior mandibular notch percutaneously and it appeared to have afferent and efferent effects.

The maxillomandibular relationship during the Myo-monitor stimulation (myocentric) in normal subjects coincided with centric occlusion (habitual occlusion) in 7 out of 10 subjects and three showed a slightly posterior position (0.20.4 mm) from centric occlusion, but anterior from centric relation (retruded position or terminal hinge position). In edentulous subjects without upper denture, the vertical movement distance of the mandible was gradually increase following increase stimulating intensity showing individual maximum values between 4.6 mm and 7.2 mm.

The mandibular position during the pause of stimuli, both in normal and edentulous subjects was constantly stable in a range of clinical rest position.

Williamson, E., and Marshall, D. Myo-monitor rest position in the presence and absence of stress. TM Facial Orthopedics and Temporomandibular Arthrography. ed. Williamson, Vol 3, No. 2, 1986.

The exact mechanism by which the Myomonitor affects the resting posture of the muscles is not known. One may hypothesize three mechanisms. The first might be a negating effect on the muscle spindle, inhibiting impulses from causing the muscle of the spindle from contracting and, therefore, taking tension off the nuclear bag. The might occur at either the mesencephalic or motor nuclei.

Secondly, TENS units in some way allow increase production of endorphins and enkephalins - the body's own opiate type substances. This might decrease the effect of the reticular formation in the hypothalamus. Therefore, fewer impulses would be discharged via the descending tracts to the trigeminal nucleus and subsequently, fewer motor impulses to the muscle of the spindle, which would relieve tension on the nuclear bag.

A third hypothesis might be that the repetitive stimulus of the Myomonitor causes direct contraction of the skeletal muscle, thus causing it to relax. Dixon et al (1967) reported that repetitive electrical stimulation of skeletal muscle at a rate less than 100 times per minute reduced the accumulation of noxious byproducts and improved the physiologic state of the muscle. There have been conflicting reports in the literature regarding the method by which the Myomonitor actually causes the muscle to contract. One report suggests that the muscle contracts by direct muscle depolarization rather than by neural stimulation at the motor end plate (Bessette & Quinlivan, 1973). Therefore, such a contraction would be non- physiologic.

The antithesis to this view was presented by Jankelson in a subsequent paper (1975).

In an attempt to resolve this conflict, two patients undergoing orthognathic surgery were treated with the Myomonitor prior to being intubated for general anesthesia. At the time of intubation, they were given succinylcholine as a muscle paralyzer. Succinylcholine acts by competing with acetylcholine at the myo-neural end plate, and therefore, no neurally stimulated muscle contraction can occur. The only way a muscle can contract under such conditions is by direct depolarization of the muscle itself. With the Myomonitor evoking electrical impulses, there was no muscle contraction either instance (Williamson and Bays, 1985). This information would support the conclusion that the Myomonitor is transmitted neurally.

LOCAL PHYSIOPATHOLOGY OF MUSCLE AND MYO-MONITOR EFFECT

INTRODUCTION

The physiopathology of muscle pain and dysfunction is much better documented in the medical literature than the dental literature. Following are articles related to histo-chemical phenomena involved with Myo-monitor therapy.

Dixon, H. and Dickel, H.A. Tension headache. J. Northwest Medicine. Vol 66, pp. 817-820, Sept. 1967.

The electromyographic check shows a general increase in all muscle output and frequency of firing, but in the muscles served by the motor roots of the cranial nerves, and the first, second and third cervical nerves, there is increased amplitude and increased rate of firing, as one observes in a tense, fatigued muscle. If the patient has sharp pain in the supra-orbital or temporal area the myogram from muscles in these areas will often show the high pitched firing of stretched, fatigued muscle. When the tension headache is occasional, the records show variation in amplitude, but when the headache is constant or long extended, we have the rapid firing seen in the fatigued muscle.

Tension headache is actually one of the symptoms of the anxiety tension state. Rigid tightness of the neck and disturbance of the head, neck, eye reflex system are due to overflow from guarded muscles of the body. The neck muscles tighten most when the individual is alerted by an alarm mechanism. They maintain tightness until the other muscles have been released for some time. Thus muscles in the neck are tense for longer periods than are other muscles. Twenty to 30 percent reduction in the energy of these muscles, as a result of being overly tense, causes a greatly reduced speed in the relaxation phase and, as a consequence, tension fatigue spasm results.

Years ago Ranson outlined the possible connections in the nervous system that would produce these effects. His diagram (Figure 1) was remarkably correct in view of present neuroanatomical findings.

With the existence of generalized muscle guard, inflow from the skeletal muscle causes alteration in hypothalamic control, producing stress symptoms. In head and neck regions all of the muscles served by the motor roots of the cranial nerves show increase in firing that lasts for some time after the tension disappears. This spread includes spinal nerves 1 to 11. Thus the disturbance of head-neck-eye balance. Because of the constancy of overflow into these muscles the disturbances of head, neck and eye balance produce delay in relaxation from fatigue spasm, resulting in the tension-fatigue headache.

TREATMENT

In treating the patient we teach him that control should be relaxation not tension and that the fatigued muscle will not stretch. Experimental work with the myograph and chemical analysis indicates that fatigued muscle restores its energy in light, free motion at a rate below 60 contractions per minute. Fatigue spasm can be reduced by electric stimulation. The device used should deliver a fraction of a milliampere, at around 100 volts, in a diphasic wave, at rate of 40 to 60 impulses per minute.

The tension headache can be permanently relieved by teaching tension control and by restoring energy to the muscle that is in fatigue spasm.

Examination of the patient with a severe neck spasm produced by a sudden forward-backward movement of the head, often elicits no evidence of root injury but does reveal muscle trauma.

The strain may leave a fatigue spasm that will continue indefinitely. In 70 percent of the "whiplash" cases we have checked, there has been no root injury. But, due to emotional distress and physical pain, the patient builds up adequate tension to keep the neck and some of the facial muscles in fatigue spasm. We have found that any attempt to reduce this spasm by stretching tends to increase it, but it can be relieved with conditioned relaxation, and light myopulse exercise to restore energy and thus flexibility.

Dixon, H.H., and O'Hara, M. Fatigue contracture of skeletal muscle. J. Northwest Medicine. Vol 66, pp 813-816, Sept. 1967.

Isolated muscle from the frog will develop contracture when directly stimulated at the rate of 40 impulses per minute. It will also develop contracture from chemical change, temperature change, and from trauma. Accompanying contracture, definite chemical alterations occur. In 1928, Dixon, Davenport, and Ranson, measured the phosphate fractions in muscle and showed that a sharp reduction in phosphocreatine always accompanied the change in physical state (Dixon, et al, 1929).

Contracture in mammalian muscle may be produced by rapid stimulation; interruption of cortical inhibitor fibers; chemical agents, such as tetanus toxin; inaction (casting); and trauma. In each case the chemical changes occurring in the phosphate fractions are similar. If the contracture is continued over a period of time it will become a fixed state, either in extension or flexion, defined by Ranson as myostatic contracture (Ranson, et al, 1927 and 1929; Dixon, et al, 1927).

This investigation deals with the comparative evaluation of myography, chemistry, and physical performance of the muscle.

We see this reduction...when there is protracted tension; when there are interferences in muscle function and circulation; and when there is strain or injury. In acute tension the normal cortical inhibition, which would protect the muscle from fatigue, is probably rendered inoperative by the intensity of the interference of somatic emotional function. We find in agitated, depressed people, lowered phosphocreatine, increased inorganic phosphate, and myographic findings characteristic of fatigue (Dixon, et al, 1952). The physical performance shows slowing in the relaxation phase.

In neck spasm due to trauma (whiplash) the physical state shows marked slowing of the relaxation phase, and the myographic recording shows the increased amplitude seen in fatigue spasm or, in extreme cases, in myostatic contracture. In prolonged episodes of rheumatoid arthritis the flexor muscles show the output of fatigue spasm, the extensors, the output of myostatic contracture. Myographic records from several hundred cases of tension headache show increased myographic firing in the upper third of the trapezius, and there is often a similar firing in the temporal, or other muscles served by the motor fibers of the cranial nerves and by the reticulo spinal flow.

CONCLUSION

Reduction of fatigue spasm or myostatic contracture can be accomplished by the use of compounds which increase the high energy phosphates, and by mild, rhythmic, muscle movement. With recovery of normal physical response myographic tracings are restored to normal. We believe that in conditions where there is extreme reduction of muscular energy (anxiety states- - tension headaches, muscular spasms, rheumatoid disease) the myographic evaluation of muscular energy can contribute to diagnosis, can assist in determining methods of therapy and can aid in the evaluation of therapeutic agents.

Rodbard, S., and Pragay, E.B. Contraction frequency, blood supply, and muscle pain. J. of Applied Physiology. Vol. 24, No. 2, Feb. 1968.

Repetitive contraction of an ischemic skeletal muscle is accompanied by the local development of pain which progresses to such severity that it brings the exercise to a halt (Zak, 1921). Intermittent claudication is a similar syndrome in which walking is hobbled and halted by pain or fatigue (Lewis et al, 1931).

Obstruction of blood flow does not, of itself, produce the pain sensation. The symptoms are probably not due to oxygen depletion since high oxygen concentrations in the breathing mixture do not affect the rate of development of pain (Park et al, 1962). Kissin (Kissin, 1934) suggests that the breathing of hypoxic gas mixtures can induce pain in exercising skeletal muscle. However, Lewis (Lewis, 1942) noted that lack of oxygen was an insufficient factor since arrest of blood flow to the arm for 20 minutes fails in the resting arm to produce or expedite the pain under consideration. Kissin found that pain appeared earlier in generalized hypoxemia than when air was breathed; however, the central effects of hypoxia could not be differentiated from those at the exercising muscle.

Contraction appears to be necessary for the development of pain, apparently due to a metabolite produced in association with the process of shortening. The metabolite is not a breakdown product of glycogen since patients with McArdle's syndrome, who have a deficiency of the phosphorylase that converts glycogen to lactic acid, develop severe pain during ischemic exercise (McArdle, 1951).

The quantitative nature of the pain response to ischemic exercise offers a means for the analysis of the mechanisms involved. The quantity of the metabolite produced appears to be related to the total mechanical tension developed by the muscle, calculated as a function of the number of contractions, the load, and the duration of each contraction (Horisberger et al, 1961; Park et al, 1962).

Rasmussen, O.C., Bonde-Peterson, F., Christensen, L.V., and Moller, E. Blood flow in human mandibular elevators at rest and during controlled biting. J. Oral Biology. Vol. 22, pp 539-543, 1977.

SUMMARY

Blood flow in the anterior temporal and masseter muscles was estimated bilaterally by local clearance of $^{133}\text{Xenon}$ with the mandible at rest, during biting and in a subsequent period of rest. Activity in the same muscles during biting was measured in terms of the mean voltage of their surface electromyograms and of the bite force at first molars in the right side. During biting for 90 s at 22-37 per cent of maximal electrical activity or 45.55 per cent of maximal bite force, blood flow did not differ from that in the previous period of rest; after biting, blood flow increased about 10 fold indicating a marked post-exercise hyperaemia. During biting in the intercuspal position at above 25 per cent of full effort, blood flow was less than 15 per cent of that after contraction. The effect of biting at strengths below 25 per cent of full effort varied from almost total circulatory arrest to flow values similar to those after biting.

INTRODUCTION

Pain and soreness in the muscles of mastication are significant symptoms and signs in patients with functional disorders of the chewing apparatus. Local pain may arise in ischaemic skeletal muscle during contraction (Lewis, 1942, Dorpat, 1952; Rodbard and Pragay, 1968). Both sustained contraction and rhythmic contractions at high rate may also be accompanied by local pain due to obstruction of blood flow caused by the contraction itself (Dorpat, 1952; Rodbard and Pragay, 1968).

In patients with functional disorders of the chewing apparatus, pain in the temporal and masseter muscles is associated with increase of their activity when the mandible is at rest (Lous, Sheikoleslam and Moller, 1970). Pain may arise in these muscles after experimental clenching and grinding of teeth (Christensen, 1967, 1970). Therefore, impaired blood flow due to contraction might be a source of pain in the muscles of mastication. This assumption is not ruled out, because some blood flow may continue during clenching and grinding (Bonde-Petersen and Christensen, 1973) unless the degree of muscle activity is accounted for.

Our purpose was to determine the influence of isometric contraction on blood flow in the elevators.

The right and left anterior temporal muscles and the right and left masseter muscles were studied in pairs during two separate sessions.

ELECTROMYOGRAPHY

The electrical activity in the test muscles was picked up by bipolar surface electrodes, amplified by difference amplifiers (DISA. type 14C10) and recorded simultaneously with the mean voltage (DISA, type 14C20) on an ink-jet recorder (Siemens Mingograph EMT 1600). The degree of activity during contraction was measured as the average level of the mean voltage (Moller, 1966, 1974).

Lasagna, M., and Orland, C. Modificazione die flussi ematici muscolocutanei indotta dallo stimolazione neurale transcutanea ischemia e dolore nella patologia oclusale. J. Odontostomatologia e Lymplantopratesi, 1986.

In the following research, 12 subjects were examined, of which 5 male and 7 female, of age comprised from 22 to 50 years. That sample of patients has presented subject with serious algic dysfunctional symptomatology in action, and others which did not present a subjective symptomatology worthy of note, also with evident occlusal alteration.

All patients were in good general condition of health and they were not at that moment under any medical therapy which could alter the cutaneous vaso-motorial response by pharmacological way.

The values of cutaneous nutritional flows were measured in correspondence of the anatomic seats of the anterior and the posterior temporalis muscles in conditions of usual rest position and after having subjected the patient to pulsation with the Myo-monitor for times sufficient to induce relaxation controlled through electromyographical evaluation at the level of the masseter and anterior temporalis muscles.

For the measurement of the haematic nutritional capillary flows, it was made use of a laser doppler velocimeter.

The average doppler frequency is linearly correlated to the haematic flow, as confirmed in vivo by studies conducted on human skin by means of the Xenon-133-wash-out technique.

Every recording was preceded by calibration for the zero. The probe was then rested on the portions of the skin under examination. The duration of the gap of measurement for every single portion examined was prolonged until the achievement of a stable recording.

The purpose of our research was to evaluate the effect of TENS stimulation on musculo-cutaneous perfusion. The functional rhythmic contractions, interrupted by gaps of relaxation do not cause pains unless the muscle is not ischemic; the pain which is determined by an ischemic muscle is called angina if it occurs in the cardiac tissue, claudicatio intermittens at the level of lower limbs. For what concern the cranium-mandibular district a similar aetiopathogenetical causal can be indicated in the determination of the painful affections typical of the MPD (myofacial pain dysfunction). The experimental by Lewis on the muscular pain is one of the classic research of the human physiology. He disposed of a subject which put in motion an ergograph simultaneously to the state of ischemia produced by a pneumatic coupling of sphygmomanometer. The function produced pain in the time of 24-45 seconds which became very high after 60-90 seconds.

Because it seems that the painful stimulus can be accumulated, Lewis and his collaborators concluded that it could be represented by a chemical substance that arise from the process of contraction, event that is inevitably present in the occlusal pathology of disnociceptive origin. This hypothetical metabolite was denominated "P Factor". It seems to be a normal product of the muscular metabolism, produced either in state of relax and or activity, and it seems to be able to stimulate the pain terminations only when it is accumulated in discreetly abundant quantity. Therefore it appears evident that being this substance produced by muscular contraction, which at his own time induce a reduced haematic blood flow, by the mechanical compression of the muscular blood vessels, it can be difficultly removed from the ischemic circulatory stream.

It will be creased in this way a sort of closed circle contraction - ischemia - pain, very similar and to it superimposable, to that which provocate in the states of contraction a lack of supply of oxygen and then a missed process of phosphorylation ATP-ADP.

Of the many agents which can represent the P Factor (anossia, variation of the pH, lactic acid, potassium, histamine) it can be excluded the lactic acid and the substances intermediate of the Krebs cycle. The potassium, according to Dorpat, is the more probable.

Even further studies have confirmed that the skeletal muscle is relatively poor of algoceptor nervous terminations.

Blood flow values measured after Myo-monitor pulsing in district characterized by a pathological muscular tone, are higher than those measured after pulsing in districts characterized by a physiological muscular tone.

This observation may be compatible with a phenomenon similar to that of post ischemic reactive hyperhemia.

The capillary blood flow, therefore should return in the range of normal values in a relatively short period of time.

To confirm this hypothesis, it would be necessary the blood flow monitoring, during and for several minutes after neural stimulation.

The study of a possible correlation between electromyographic and blood flow values demonstrated that these two parameters are independent under physiological situations, being the nutritional blood flow function of several different variables, like intrinsic vascular tone, muscular activity, and so on.

The chronic pathological muscular hypertone, secondary to an occlusal disease, on the contrary, induces a mechanical relative ischemia, and the blood flow becomes mainly function of the muscular tone. The relief of oro-facial pain is therefore secondary not only to a neurologic mechanism.

We demonstrated, as suggested by Yavelow et al, that mild rhythmic muscle movement increases the local circulation of blood, which reduces the interstitial edema and accumulation of noxious tissue metabolites.

It has to be mentioned, in addition, the possible beneficial action of TENS in treating chronic pain by stimulating the production of several beta-lipoproteins with analgesic activity.

TENS action decreased EMG values at the level of anterior temporalis muscle from $3.8+1.93$ to $1.6+0.43$ (P, significance index, less than 0.001).

This numerical EMG values were obtained by the printer of the Myotronics Bioelectric Processor EM2. We can see in this slide the blood flow tracings before and after Myo-monitor pulsing.

A similar result has been obtained at the level of the masseter muscle. The EMG values for this muscle has been decreased by neural stimulation from $3.6+1.71$ to $0.9+0.11$ (P less than 0.001).

Muscular relaxation induced a significant increase in musculocutaneous nutritional blood flows at the level of the anatomical sites of temporalis anterior and temporalis posterior muscles.

At the level of the temporalis anterior muscle the capillary blood flow showed an increase by TENS from $3.61+1.24$ to $4.79+1.72$ arbitrary units (P less than 0.01).

TENS produced also an increase in blood flow at the level of the temporalis posterior muscle from $2.77+1.02$ to $3.84+0.94$ arbitrary units. (P less than 0.05).

A significant inverse correlation was present between electromyographic and blood flow values (r, correlation index, = -0.6599; P less than 0.05) in the districts characterized by a pathological baseline muscular tone, corresponding to contraction.

In the districts with a normal physiological baseline muscular tone, on the contrary the two variables are independent.

Our study confirmed that the electrical stimulation of the 5th and 7th pair of cranial nerves induce a decrease of the electrical activity in the muscles served by these nerves. In this way a physiological state of muscular electrical activity is obtained, and in consequence, we observed a mandibular spatial repositioning, as well as an improved musculo-cutaneous perfusion. An increase in capillary blood flow in the district under exam was more evident when a base line pathological muscular tone was present.

Thomas, N.R. Spectral analysis in the pre- and post-TENS condition. TM Presented International College of Cranio-Mandibular Orthopedics, Oct. 1986.

Muscle pain is a common symptom of functional disturbances of the masticatory system. Experimentally induced hyperactivity of the masticatory musculature produces similar symptoms (Christensen, 1979; Scott and Lundeen, 1980) supporting the hypothesis that muscle pain is produced by muscle fatigue (Jankelson, 1969, 1975; Laskin, 1969; Derijk et al, 1977; Palla and Ash, 1981; Lindstrom and Helsing, 1983).

Integrated electromyography (IEMG) has commonly been used as a quantitative measure of activity required to maintain a certain level of muscle tension as well as to differentiate between muscle relaxation and fatigue since it has been shown that relaxation is accompanied by minimal I.E.M.G. and fatigue by increasing I.E.M.G. as the time of fatiguing contraction progresses (Viitasalo et al, 1978). Many studies have confirmed the existence of a straight line (or proportional) relationship between muscle force and integrated E.M.G. (Inman et al, 1952; Lippold, 1952; Edwards and Lippold, 1956; Bigland and Lippold, 1954; Milner-Brown and Stein, 1975).

Indeed it has been demonstrated by McKenna and Turker (1978) that the IEMG will reduce as the jaw opens for a fixed muscle tension or constant load (see also Nordstrom and Yemm, 1974). So a decrease in E.M.G. activity is not necessarily a true indicator of elevator muscle relaxation if the jaw is simultaneously opened. Nor is the increase in jaw opening necessarily an indicator of muscle relaxation since this may also occur in muscle fatigue.

Thus without satisfactory evidence to the contrary it may be argued that T.E.N.S., rather than producing relaxation, fatigues the masticatory musculature so that as the load of the mandible opens the jaw there is a reduction in E.M.G. activity as a result of lengthening of the fatigued muscle.

Fortunately there is a simple procedure that can be used to directly test the effect of T.E.N.S. on fatigued masticatory musculature.

In 1912 Piper (Piper, 1912) observed that the peak frequency of the myoelectric signal decreases during fatiguing muscular contractions. Since that time it has been repeatedly shown that fatigued muscle is accompanied by a decrease in the frequency of its EMG activity causing the peak power frequency spectrum to shift to lower frequencies (Chaffin, 1969; Kwatny et al, 1970; and Viitasalo and Komi, 1978). Indeed Palla and Ash (1981) and Lindstrom and Hellsing (1983) demonstrated a similar shift in peak frequency for fatigued masticatory musculature.

It has also been shown by Vrendenbregt and Rau (1968) that a shift in the spectral peak of E.M.G. frequencies during fatigue is only minimally affected by electrode orientation or muscle elongation. Hence it was decided to test the hypothesis that T.E.N.S. does produce muscle relaxation and not muscle fatigue by utilising spectral analysis of elevator E.M.G. on normal and T.M.J. patients pre and post T.E.N.S.

Subjects were seated in a dental chair with the Frankfurt plan kept horizontal. Threshold transcutaneous electroneural stimulation was applied with a pulse duration of 500 μ sec., at 1 1/2 sec intervals to the preauricular region overlying the masseteric notch. M.K.G. and E.M.G. instrumentation was applied as defined in the Myo-tronics manual with the addition of gnathodynamometry for force monitoring.

EMG recordings were made prior to TENS stimulation while the subject was at rest for 20 minutes with a measurable freeway space varying between 2.2 and 3.1 mm. The subject was then required to maximally clench (MVC) for 10 sees while EMG magnetic tape recordings were taken using a Sony taperecorder (T.C. Fx600). Finally the subject was asked to maximally clench until fatigue developed. A further ten second tape recording was taken. The subject was then provided with 20 mins of TENS as described above. This procedure was repeated a second time with the exception that 20 minutes rest replaced the TENS treatment.

RESULTS

NORMAL SUBJECTS

The I.E.M.G. was seen to increase with the patient's expression of increasing fatigue. As fatigue developed the spectral peak density gradually shifted from 125 Hz at rest to 75 Hz (Fig. 1). Twenty minutes of TENS like rest restored the spectral peak to 125 Hz for normal control subjects with sharper discrimination (Fig. 2).

T.M.J. SUBJECTS

However for T.M.J. subjects it was observed that for both the pre and post fatigued condition the frequency spectrum peaked at 75 Hz (Fig. 3). No amount of rest or wearing of a Lucia jig splint could restore the peak to normal relaxed levels (Fig. 4). T.E.N.S. however succeeded in relaxing the musculature of the T.M.J. masticatory system shifting the spectral peak from 75 Hz to 125 Hz.

DISCUSSION

It is clear that masticatory musculature of T.M.J. subjects as opposed to non-T.M.J. subjects exhibits fatigue. Rest alone does not resolve the masticatory muscular fatigue. It was also found in another set of experiments that rest with a Lucia jig also fails to eliminate the fatigue.

T.E.N.S. however does resolve the fatigue of normal and T.M.J. subjects. The failure of rest to restore normal muscle activity suggests that masticatory muscular fatigue includes a metabolic deficiency such as relative ischemia which cannot be resolved by rest alone (Mortimer et al, 1970; Kovacs, 1942; Stephens and Taylor, 1972; Merton, 1954). T.E.N.S. may act by improving muscle function though removing muscle metabolites and/or reversing muscular ischemia. Further studies are underway to answer this question.

We therefore have in E.M.G. spectral analysis a relatively simple method for assessing the presence or absence of muscle relaxation or fatigue as well as providing a ready procedure for objectively analysing treatment modalities. Certainly T.E.N.S. is effective in resolving masticatory muscle fatigue exhibited in both normal and T.M.J. dysfunction subjects.

MYO - MONITOR EFFICACY

INTRODUCTION

Following are articles supportive of the Myo-monitor (i.e. low frequency TENS) efficacy in treatment of TMD. The controlled studies of Pantaleo and Prayer- Galletti are of particular interest.

Pantaleo, T., Prayer-Galletti, F., Pini-Prato, G. and Prayer-Galletti, S. An electromyographic study in patients with myofacial pain-Dysfunction syndrome. Bull. Group. mt. Rech. Sc. Stomat. et Odont. Vol. 26, pp. 167-179, 1983.

Recently dental research has turned to neuro-muscular system: many dental procedures, in order to be entirely successful, require that the masticatory muscles are relaxed and perfectly balanced. The use of the transcutaneous electrical nerve stimulation (TENS) has been introduced, obtained with adequate stimulators, such as the Myo-monitor (Myo-tronics) (Jankelson 1975, Jankelson 1978, Wessberg 1981): TENS has been able to relieve pain and eliminate the sustained muscle tension of the masticatory muscles of patients with myofacial pain-dysfunction (MPD) syndrome (Laskin 1969), combined with occlusal malrelation, which may be the primary cause of MPD syndrome (Lindblom 1953, Ailing 1977).

Mandibular Kinesiography (MKG) (Jankelson 1975) records the position and the movements of the jaw and studies objectively the occlusal malrelations and their corrections which in many cases are achieved by means of acrylic splints which lead to the orthodontic and/or the prosthetic treatment for a stable resolution of the syndrome (Jankelson 1979).

The mandibular rest position is an important starting point for dental treatment. In normal subjects, in an upright position with the lips slightly in contact but the teeth not together, during the voluntary muscle relaxation, there is virtually no activity in the masticatory muscles investigated (Vitti 1975, Vitti 1977), except for the subjects with occlusal interferences

Therefore, in accordance with Jankelson (Jankelson 1979), the mandibular rest position seems to be determined by passive factors and it is in that balanced state that all the muscles are relaxed at their resting lengths. In the rest position so defined, the normal freeway space recorded with the MKG, is about 1-2 mm; the most favorable situation for the intercuspation is achieved when the jaw moves from the rest position through the interocclusal space for about 1-2 mm on the isotonic relaxed trajectory obtained with the Myo-monitor pulsing (Jankelson 1979). In normal subjects, the voluntary fast closure of the jaws follows this isotonic relaxed trajectory or a trajectory very near to it. If the intercuspation is placed away from the relaxed trajectory, in order to have the same fast movement of closure, it is necessary that the masticatory muscles adjust themselves to avoid excessive variations and corrections.

MKG recordings show that the occlusal position determines that postural adjustment (adaptive holding position) and a different trajectory, too (Jankelson 1979). Such an adaptive holding position could be maintained by neuromuscular spindles which are particularly plentiful in the jaw closing muscles (Voss 1935, Freimann 1954, Cooper 1960) which show stretch reflex responses that are absent in the jaw opening muscles (Hugelin 1956, McIntyre 1957, Hannam 1972, Lamarre 1975, Neilson 1979). Therefore a wrong occlusion appears to program an abnormal muscular activity at rest and abnormal patterns of muscle contraction during the mouth closure with trajectories which are different from the isotonic relaxed one. The prolonged and/or abnormal muscular activity can cause muscular pain (Rodbard 1968, Miller 1979) which in turn provokes motor reflexes so that a vicious circle may be established (Zimmermann 1979): that could be the basis of the MPD syndrome.

The relationship between the electromyographic (EMG) activity of the masticatory muscles and some types of malocclusion has been investigated by earlier researchers (Moyers 1949, Liebman 1960, Moss 1965, Grosfeld 1965, Ahlgren 1966, Ahlgren 1973, Moss 1974, Moss 1975, Pancherz 1980), chiefly regarding temporalis and masseter muscles.

Chaco (Chaco 1973) has reported that the levels of EMG activity of the masseter muscle in patients at rest are higher than the levels in healthy volunteers; there is also evidence that those patients showed an excessive activity of the masseter muscle under stress (Yemm 1969, Thomas 1973)

The present EMG study was undertaken in order to attempt to clear up some aspects of the pathogenesis of the pain and of the muscular dysfunction induced by occlusal malrelations. Preliminary results have been previously presented (Pantaleo 1980).

METHODS

The subjects studied were 5 healthy volunteers (3 males and 2 females aging from 19 to 38 years) and 11 MPD syndrome patients (6 males and 5 females ranging in age from 20 to 42 years) who gave their informed consent to the experimental procedures. All the subjects were recorded with Jankelson's Mandibular Kinesiographs (Model K5R, Myo-tronics). The EMG was recorded from the temporalis and the masseter muscles of the same side of the body with cup surface electrodes (8 mm diameter) filled with electrode jelly and fastened to the skin with adhesive strips.

The electrical activity of the muscles was amplified (Tektronix 2A61 AC differential amplifier) and displayed on a double beam oscilloscope (Tektronix 565) and monitored by an audiometer (Grass AM4B). Muscle action potentials were full-wave rectified and integrated (IEGM) over time (low-pass filter, time constant 100 ms) in order to provide a one-directional integrated trace describing the time course of EMG events. Furthermore, the IEMG may allow a more quantitative evaluation of muscular activity (arbitrary Units). The integrated activity was fed to the same oscilloscope after amplification (Tektronix 3A74 Amplifier). The photographs were taken with a Kymograph camera Grass C4.

The EMG activity was studied both at rest (with the subjects sitting in an easy and comfortable upright position in an adjustable chair, with their masticatory muscles relaxed, their lips slightly in contact but their teeth not touching) and during the maximal biting in the intercuspal position. The EMG study was repeated after the application of TENS in all tested subjects and also after the correction of the occlusal malrelations only in patients with MPD syndrome.

The TENS was applied for periods varying from 10 to 30 minutes in order to achieve muscle relaxation using the Myo-monitor (J3 Model, Myo-tronics).

The correction of the occlusal malrelation was performed with the application of acrylic splints built according to the Myo-monitor procedure (Jankelson 1978, Jankelson 1979) and by checking with the MKG analysis.

RESULTS

Control subjects. In the asymptomatic controls, the Kinesiographic analysis showed a normal vertical dimension (1-2 mm), and a voluntary closure trajectory which corresponded to or was very close to the relaxed trajectory obtained with the Myomonitor. No significant increase in the freeway space was found in control subjects after 20.30 mm of Myo-monitor pulsing.

During the rising of the mandible from rest position only the temporalis muscle presented noticeable EMG activity before the contact of the teeth.

Patients with MPD syndrome; on the MKG analysis they showed the following alterations: 1) difficulty in relaxation; 2) decrease of vertical dimension; 3) abnormal posterior displacement of the jaw during closure; 4) closure trajectory from rest position to centric occlusion different or continually varying from the relaxed trajectory.

The EMG study revealed an involuntary muscular activity at rest in the anterior portion of the temporalis muscle in all tested positions. After a voluntary contraction in the EMG activity came back slowly to the previous levels showing a delay in muscle relaxation. The TENS application for 20-30 mm. produced a remarkable pain relief and caused the disappearance of the involuntary activity at rest; nevertheless a single mouth closure with the teeth in contact was sufficient to cause a resumption of the sustained EMG activity.

The pain and the combined symptomatology of the MPD syndrome also appeared again more slowly in a period varying from only a few to 24 hours.

When the occlusion was corrected with acrylic splints in order to reach normal MKG recordings, the EMG patterns also improved: the involuntary EMG activity greatly decreased and sometimes disappeared after the splint was applied. TENS induced a better relaxation even after the occlusal correction. Under these conditions, the closure of the mouth even if repeated several times showed a very little tendency to induce again an abnormal EMG activity at rest.

All MPD patients displayed abnormal EMG patterns during the maximal biting in the intercuspal position, i.e., the EMG activity during the voluntary contraction increased slowly to a low maximum level that was not maintained (progressive decrease of activity).

After the correction of the occlusal malrelations with splints, EMG patterns improved and appeared more similar to those of control subjects: the activity increased more quickly to a higher level than was maintained during the voluntary contractions (plateau).

In the mandibular rest position normal subjects with normal MKG tracings did not show any EMG activity in the masticatory muscles investigated according to previous research (Vitti 1975, Vitti 1977, Voss 1935). This fact confirms the hypothesis that the mandibular rest position is determined by passive factors (Jankelson 1979). The abnormal involuntary activity found in patients with occlusal malrelations together with MPD syndrome, especially in the temporalis muscle which is the most important for posture, confirms previous observations (Funakoshi 1976, Chaco 1973): this activity seems intense enough to cause muscular pain and a vicious circle leading to the MPD syndrome (Miller 1976, Rodbard 1968, Miller 1979, Zimmerman 1979). The TENS performed by the Myomonitor is able to achieve muscular relaxation and pain relief (Jankelson 1978): the MKG and the EMG, as shown by the present results, give evidence of such muscular relaxation.

The TENS effects can be explained by various mechanisms and those in the Central Nervous System (CNS) seem to be the most important (Elzak 1979, Andersson 1979).

The Myo-monitor TENS seems similar in some aspects to the one previously used by other authors in the facial area (Andersson 1979, Andersson 1977, Andersson 1977) which was able to give analgesia especially if intrasegmental and causing muscle contraction (electro - acupuncture).

Nevertheless, the TENS has temporary effects because it does not eliminate the primary cause hypothesized for the MPD syndrome (Lindblom 1953, Ailing 1977); the mouth-closing in MPD patients reestablishes the abnormal EMG activity, suggesting an abnormal involvement of the periodontal and/or muscular afferent activity. Therefore, present EMG observations support Jankelson's suggestion that the adaptive holding position of the jaw is determined by the occlusal position (Jankelson 1979).

The decrease of the abnormal EMG activity after the correction of the occlusal malrelations with acrylic splints confirms this interpretation and points out that an occlusal discrepancy can be the cause of an abnormal EMG activity and of the consequent MPD syndrome.

These observations agree with the hypothesis that the MPD syndrome pain is due to a muscular hyperactivity (Yemm 1976) and that is possible to obtain the same clinical signs of the MPD syndrome placing the muscles of mastication under stress by fitting healthy volunteers with a complete set of dentures that had faulty occlusion (Brill 1962)

The abnormal EMG patterns during maximal biting in the intercuspal position without the splint correction indicate that the occlusal malrelations induces some alpha motoneurons inhibition; this may originate from dental and periodontal receptors abnormally stimulated in consequence of the occlusal malrelations (Bratzlavsky 1976). Similar observations were previously reported in children with malocclusion (Pancherz 1980).

In conclusion, the EMG study of the masticatory muscles combined with the MKG analysis seem to be a useful tool for studies on the pathophysiology of the stomatognathic apparatus; this approach may be also useful from a diagnostic and therapeutic point of view.

SUMMARY

An electromyographic (EMG) study of ipsilateral masseter and temporalis muscles was undertaken in healthy volunteers and in patients with MPD syndrome, with the aim of getting further insight into the pathophysiology of this disease. Unlike controls, patients had abnormal MKG features and displayed involuntary sustained EMG activity at rest, chiefly in the temporalis muscle.

Transcutaneous electrical nerve stimulation (TENS) performed with the Myo-monitor induced relaxation and relief of pain; these effects were however reversed by voluntary mouth closures.

The correction of occlusal position by acrylic splints was able to induce a persistent reduction or a suppression of the abnormal EMG activity at rest and a good relief of pain; moreover, after the correction, higher levels of EMG activity were found during maximal biting in the intercuspal position.

Mechanisms underlying these effects were discussed and in particular it was suggested that abnormal afferent activity from periodontium and jaw muscles may contribute to the establishment of sustained contraction leading to muscular pain, which in turn may cause reflex muscle activity in a vicious circle.

Wessberg, G.A., and Dinham, R. The Myo-monitor and the myofacial pain dysfunction syndrome. Journal of the Hawaii Dental Association. Vol 10, No. 2, Aug. 1977.

The Myofacial Pain Dysfunction Syndrome (MPD, TMJ Syndrome, Craniocervical Syndrome) has plagued dentistry for many years. Therapy for this type of pain has been highly imaginative. A few of the more common modalities mentioned (Ramfjord 1971) are occlusal adjustment, occlusal bite splints, immobilization of the mandible, drug therapy, placebo, diathermy, physical therapy, sclerosing agents, psychotherapy, and surgery. Recent studies of mandibular movement (Jankelson 1976) stress the importance of a "muscularly oriented occlusal position" for the treatment of the MPD Syndrome.

Jankelson (Jankelson 1976) assumes a compromise in these trends of thought actually exists. He describes a relatively precise PRPM at any given stage of development that fluctuates within a minimal range of normal as determined by states of equilibrium within the mandibular musculature.

The postural rest position of the mandible (PRPM) is by definition (Academy of Denture Prosthetists, Glossary of Prosthetic Terms, 1956) the mandibular position assumed when the head is in an upright position and the involved muscles, particularly the elevator and depressor groups, are in equilibrium in tonic contraction, and the condyles are in a neutral, unstrained position.

MATERIALS

The Jankelson Myo-monitor was the instrument used to obtain the myocentric position in patients presenting with symptoms associated with the MPD Syndrome. As described in the instruction manual, (Myo-monitor Instruction Manual, 1976), the Myo-monitor delivers a 2 millisecond impulse at 1.5 second intervals to the motor centers of the fifth and seventh cranial nerves. These mild, repetitive impulses are applied via extra-oral surface electrodes to relax the mandibular musculature and result in a highly controllable closure devoid of proprioceptive influences.

SUBJECTS

Thirty patients ranging in age from 14 to 56 years and in satisfactory physical condition were treated for symptoms associated with the MPD Syndrome. Among the symptoms were complaints of pain in the neck, ears, TMJ, and facial musculature. TMJ crepitus, dental hypersensitivity, and mandibular hypomobility were also present in a few cases. Tomogram radiographs were taken of the TMJ to rule out possible joint trauma or degeneration. Diazepam (Valium) was prescribed for selected patients to alleviate anxiety and facilitate muscle relaxation prior to Myo - monitor therapy.

RESULTS

The treatment results achieved in the Facial Pain Clinic for thirty patients from June 1976 to June 1977 can be seen in Table I. Symptoms were recorded as being present or absent. Treatment was considered complete if Myo-monitor therapy was rendered and occlusal adjustment or splint resulted in a remission of symptoms though the patient didn't return for definitive follow-up care. The results are termed positive in cases where there was improvement or complete remission of the presenting symptoms. Recalls are termed in a similar manner. .

SUMMARY

Thirty patients presented symptoms associated with the Myo-facial Pain Dysfunction Syndrome. All of these patients received Myo-monitor oriented therapy and nearly all of them professed some initial relief or total remission of their symptoms during the short time span of this study.

The data presented is based largely on clinical observations and patient response to comparison of their symptoms before and after treatment. Symptoms evaluated were generally related to muscle tenderness and mandibular mobility.

CONCLUSIONS

Due to clinical observations and patient response in this investigation, it is concluded that:

1. The centric occlusion position is seldom coincident with the myo-centric position of occlusion in patients who exhibit symptoms associated with Myofacial Pain Dysfunction Syndrome.

2. A Myo-monitor generated occlusal position affords some relief if not complete remission of symptoms in 90% of cases treated.
 3. Long-term follow-up studies are necessary to evaluate the success of treatment.
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Wessberg, G.A., Carroll, W.L., et al. Transcutaneous electrical stimulation as an adjunct in the management of myofascial pain- dysfunction syndrome. The Journal of Prosthetic Dentistry. Vol 45, No. 3, March 1981.

The beneficial effects of Transcutaneous electrical stimulation may include neurologic, physiologic, psychological, and pharmacologic mechanisms

Physiologic: Dixon et al. (Dixon 1967) reported on the physiologic aspects of repetitive, electrically induced depolarization of mammalian skeletal muscle. They demonstrated that repetitive depolarizations of skeletal muscle at a rate less than 100/mm in the presence of an adequate supply of high-energy phosphate reduces fatigue contracture. Yavelow et al. (Yavelow 1973) suggests that mild, rhythmic muscle movement increases the local circulation of blood and lymph, which in turn reduces the interstitial edema and accumulation of noxious tissue metabolites. Wessberg et al. (Wessberg, submitted for publication at date of this article) have demonstrated that repetitive, transcutaneous stimuli to the preauricular areas of the face of normal individuals causes a generalized reduction in the resting electromyographic activity of the muscles of mastication. The improved physiologic state of the muscle apparently promotes a reduction in spasm and pain. (Trott 1978, Yavelow 1973).

Pharmacologic: The present study was designed to evaluate the clinical effectiveness of a neuromuscular approach to the management of individuals with MPD syndrome which includes TES to the preauricular areas of the face and the creation of a stable neuromuscular-induced occlusal position.

MATERIAL AND PROCEDURE

Twenty-one patients were selected during a given time period and treated in the Facial Pain Clinic at the Queen's Medical Center for symptoms of MPD syndrome. Seven men and 14 women, ranging from 16 to 59 years of age, were chosen. All were in generally good health, presented with complete or partially edentulous dentitions, and complained of having had facial pain symptoms for up to 1 year. Seventeen of these patients had been treated by various methods prior to referral. The diagnosis of MPD syndrome was made by clinical and radiographic evaluation.

INSTRUMENTATION

Radiographs: An orthopantomograph, a dental radiograph unit, and a tomography Unit in the hospital were used to complete a thorough, radio-graphic evaluation to rule out pathologic conditions in the maxilla, mandible, TMJ, and dentition.

TES: The Jankelson Myo-monitor (Model 32) is a solid state electronic unit designed to eliminate occlusal proprioceptive influences in the mandibular musculature via TES. An externally mediated electrical stimulus of 2 msec duration at 1.5-second intervals is directed to the preauricular areas of the face. These stimuli result in a highly repetitive, isotonic mandibular closure devoid of proprioceptive input from the periodontium.

Occlusal splints: Temporary occlusal splints were fabricated when indicated with Myo-Print Sapphire acrylic resin. The technique involved a direct intraoral interocclusal registration with the mandible closing from a relaxed, muscularly determined postural rest position generated by TES

TES THERAPY

With the patient seated in an upright position, electrodes were placed bilaterally over the sigmoid notch area as directed by the instruction manual. The impulse was balanced. A minimum of 45 minutes of TES at a threshold level was completed.

TREATMENT PROTOCOL

Following initial examination and consultation, the patient's clinical symptoms were recorded as shown in Tables I through IV. Treatment sessions were conducted as follows:

First appointment: TES Therapy was performed as described. Alginate impressions were made of dental arches for diagnostic casts, if possible.

Second appointment: TES therapy was followed by direct, intraoral occlusal record as determined by TES at a stimulation level one above threshold. Evaluation of the interocclusal relationship was done to determine if implementation of a temporary occlusal splint or occlusal adjustment was indicated. The goal of adjustment was to provide free entry of the teeth into a stable occlusal position as determined by a relaxed musculature.

Subsequent appointments: TES therapy was repeated at subsequent sessions followed by necessary occlusal adjustments of the splint or dentition until a stable position was achieved. When the patient and clinician were satisfied with the results of therapy, the dental casts were mounted on an articulator and definitive treatment was discussed with the patient. For those patients on whom an occlusal splint was used, observation for a minimum of 1 year was suggested before treatment such as orthodontics, dental reconstruction, or surgical-orthodontic procedures were performed.

RESULTS

Treatment results were grossly subjective, based primarily on the patient's comparison of the pre-treatment symptoms with their status 1 year after treatment. Objective evaluations by the clinician included a comparison of muscle tenderness, TMJ noises, and mandibular range of motion. Overall treatment was assessed as being either positive (indicating improvement) or negative (indicating no improvement).

Treatments used for these 21 patients included TES for all patients, semipermanent occlusal splints for 16 of the patients, and occlusal adjustment for four of the patients. Immediate post-treatment results showed 20 positive responses and one negative response, a male with severely abraded dentition due to chronic bruxism. This is a 95% success rate.

One-year post-treatment reevaluation of the 21 patients yielded 18 positive and three negative responses. All three negative responses were women. The man with the immediate post-treatment, negative response noted improvement 3 months after insertion of the occlusal splint. This demonstrates an 86% success rate after 1 year. In the case of the three negative responses, all of which were helped initially, lack of success may be due to the fact that two of these patients discontinued the use of the occlusal splint and complained of the high cost of therapy. The third unsuccessful patient received occlusal adjustment only and discontinued therapy. In all three patients, the pain was low-grade in nature and did not significantly limit the patient's activities.

The results of treatment in Table V show that 10 of the 11 patients treated with semipermanent occlusal splints obtained favorable results

DISCUSSION

This study evaluates the immediate and long-term results of a muscularly oriented treatment regimen for symptoms of the MPD syndrome. Data obtained from post-treatment evaluation of 21 patients treated with TES demonstrated a success rate of 95% immediately and 86% after 1 year. Our data demonstrated a very high incidence of lateral pterygoid muscle dysfunction (85.7%). This suggests that discrepancies in the transverse and anteroposterior position of the mandible relative to centric occlusion are not well tolerated. Elimination of these discrepancies in maxillomandibular relations via TES and occlusal adjustment or occlusal splint placement appears to promote the long-term relief of muscle symptomatology. Attempts should be made to eliminate the splint after the patient becomes asymptomatic for 30 days, as many individuals may function satisfactorily in their existing habitual occlusion once the myospasms subside. Comparison of these results with other reports in the literature is quite favorable. However, few authors present data of long-term follow-up for other treatment modalities.

Boschiero, R., Fraccari, F., and Pagnacco, O. Analysis of the results of the use of the Myo-monitor in patients with reduced mouth opening. *MM. Stom.* Vol 35, pp 857-864, Sept. 1986.

SUMMARY

Fifteen young patients with markedly reduced mouth opening (less than 26 mm) with no severe articular alterations revealed by radiography were subjected to treatment with a Myo-monitor. The mouth opening was measured during stimulation and the data analyses mathematically. The treatment was effective in all cases. In the worst cases the opening was increased by 33.33% and the mean was 87.87%. The mean curve of increase over time showed altering phases of rapid advance and plateaux. The first stage, lasting about 45 minutes constantly produced almost no increase.

Konchak, P., Thomas, N., Lanigan, D., and Devon, R. Freeway space measurement using mandibular kinesiograph and EMG before and after TENS. *The Angle Orthodontist* October, 1988, pp 343-350.

Lack of knowledge about how physiologic influences bear upon the morphology of persons treated with orthodontics or orthognathic surgery both before and after treatment places clinicians in an unenviable position with respect to sound diagnosis, treatment planning, and prognosis. Although it is well recognized that the morphology of the craniofacial complex has functional influences (Schudy 1964, Sassouni 1969, Paolini (1970), the physiologic parameters influenced by morphology are still not well understood. This investigation expands on a previous pilot study (Konchak et al. 1986) concerned with the identification and correlation of certain morphometric and physiologic properties of the cranio facial complex related to mandibular rest position.

Vertical positioning of the maxillary and mandibular dentitions is dependent on the equilibrium between intrusive environmental forces and the eruptive forces of the supporting tissues acting on the teeth. This balance may be affected by a myriad of factors and variables involving bone, teeth, and soft tissues, including therapeutic efforts such as orthodontics and orthognathic surgery.

Orthodontists and maxillofacial surgeons have traditionally approached these relationships using descriptive methods based on clinical examination and cephalometric and/or dental cast analyses. As these emphasize static rather than dynamic factors, the physiology of the stomatognathic system, and in particular the neuromuscular system, often receive little attention.

A patient's resting vertical dimension, including the freeway space (FWS), is essentially an adaptive physiologic parameter (Mohl 1978, McNamara et al. 1978). Rest position has been defined as the neutral rest position attained by the mandible as it is involuntarily suspended by the reciprocal coordination of the elevator and depressor masticatory muscles with the upper and lower teeth separated (Niswonger 1934). McNamara et al. 1978 state that rest position is influenced by the activity of the fusimotor system of the elevator muscles through psychic input, and through stimuli from peripheral receptors such as those located in the temporomandibular joint, periodontal ligament, gingiva, tongue and palate.

Jankelson (1977) has described adaptive and true rest positions of the mandible, and thereby adaptive and true freeway spaces. Adaptive freeway space is defined as the interocclusal space that exists when the patient is instructed to voluntarily allow the jaw to relax. True freeway space is the interocclusal space present after relaxation of the masticatory musculature has been achieved, such as occurs following transcutaneous electrical nerve stimulation (TENS) with a myomonitor.

A relaxed muscle is defined as one that is neither contracted nor stretched (Ganong 1985). At this physiologic resting length the muscle is capable of exerting maximal force and maximal velocity under isometric and isotonic conditions respectively. This capability has been explained by the sliding filament theory of muscle contraction which postulates that the maximal availability of cross-bridge reactive sites is present at a muscle's physiologic resting length (Huxley 1969).

That masticatory muscle relaxation is achieved following transcutaneous nerve stimulation to the motor division of the trigeminal nerve is confirmed by post-TENS reduction in electromyographic activity, and by an increased muscle response in both force and velocity to electrical stimulation at threshold levels. A spectral analysis of voluntary isometric contraction reveals that fatigue is resolved and not induced by TENS. The power density spectrum frequency maximum shifts from a fatigue level of 75Hz to a relaxed level of 125Hz (Thomas 1987). Comparisons between muscle velocity, force dynamics, and electromyographic spectral analyses confirm that an electrical noise level below 15UV indicates the attainment of physiological resting condition of the masticatory musculature.

After reviewing the results of the pilot study, it was felt that a similar study should be repeated utilizing a larger sample size, and including EMG investigation. The purpose of this research project was to:

1. Determine the percentage of patients who achieved masticatory muscle relaxation following TENS stimulation.
2. Compare adaptive and true freeway spaces.
3. Correlate adaptive and true freeway space values with cephalometric parameters that describe the vertical dimension of the face and facial proportions.
4. Compare freeway space with the Angle classification.

METHODOLOGY

Sixty-two patients seen at the University of Saskatchewan for orthodontic treatment were selected for participation in the study. No criteria for selection were used except that they had to have a natural dentition and be free of symptoms suggestive of temporomandibular joint dysfunction.

Lateral cephalometric radiographs were obtained for each patient with the Frankfort plane horizontal, and with the mandible in the centric occlusion position. From these cephalographs the sellanasion / mandibular plane angle (S N/MP) and percentage nasal height values were measured to represent common descriptive measurements of the patient's vertical dimension.

Subjects were seated in a chair and transcutaneous electrical nerve stimulation instrumentation applied utilizing the protocol established by (Jankelson 1977, Jankelson and Radke 1978 and Jankelson 1981). This consisted of the myomonitor, mandibular kinesiograph (MKG) (Myotronics Corp. Seattle, Washington). This is illustrated in the pilot study (Konchak et al. 1987). The surface EMG electrodes were applied over the right and left temporalis and masseter muscles in strict accordance with Jankelson's methodology (1981).

EMG recordings were made prior to TENS stimulation, and the adaptive freeway space was measured from the prepulsed vertical dimension of the occlusion. Subjects were then given a minimum of 40 minutes of TENS immediately prior to recording true freeway space values.

It has previously been established by Thomas (1986) that the masticatory muscles are reliably relaxed at EMG values of 14 UV or less, so this EMG criterion was used to group the patients into relaxed and non-relaxed categories.

RESULTS

Four categories of patient groups were established on the basis of the above criteria:

- Type A - relaxed before and after muscle stimulation
- Type B - not relaxed before or after muscle stimulation
- Type C - not relaxed before, but relaxed after muscle stimulation
- Type D - relaxed before, but not after muscle stimulation

The average freeway space value before the muscle stimulation was 2.6mm, and after the stimulation it was 3.4mm. These values in the pilot study were 1.8mm before and 2.9mm after stimulation. S-N/MP averaged 33.4 \div - 6.9o, and the percent nasal was 45.4 \pm 2.0%.

It is interesting to note that Group D, albeit a very small sample size, was the only group where the average FWS decreased after TENS. This was the group that demonstrated increased muscle activity after muscle stimulation.

Jankelson (1981) has previously discussed the fact that freeway space has not only a vertical but also an anteroposterior component. He found the A/V (anterior to vertical) ratio to be 1:2, whereby a closing trajectory of the mandible results in a 1mm anterior movement in conjunction with 2mm of vertical movement. This study found an A/V ratio of 1:1.8 ($r= .72$), confirming Jankelson's findings.

SUMMARY AND CONCLUSIONS

- Four categories of relaxation of the masticatory musculature were determined in patients before and after TENS.
- 58% more patients achieved masticatory muscle relaxation after TENS (50% before, 79% after).
- The average freeway space measurement increased after TENS. Differences for individual patients in their pre- and post-stimulation freeway space values, however, could be either positive or negative, as some experienced an increase in masticatory muscle activity following TENS stimulation.
- Clinical and true freeway space values are inversely correlated with the SN/MP angle, but the correlation values are low.
- Angle classifications were not correlated with freeway space.

- S-N/MP angle and percentage nasal height were inversely correlated. No correlation was found between percentage nasal height and FWS. Descriptive factors obtained from cephalometric measurements such as percentage nasal height and S-N/MP angle can be useful in diagnosis and treatment planning, but these values must be correlated with the clinical examination.
- Previously accepted and unchallenged concepts of freeway space and vertical dimension such as those postulated by Guichet (1970) and Lindegard (1953) were not borne out by our application of kinesiographic technology.
- In applying FWS values as an aide to orthodontic diagnosis and treatment planning, individual patient values are of greater significance than are group averages. In ongoing studies, individual patient's freeway space before and after treatment are being investigated to see whether this parameter is important in influencing the ultimate stability of the occlusion.

Bazzotti, L. Electromyography tension and frequency spectrum analysis at rest of some masticatory muscles, before and after TENS. *Electromyogr Clin Neurophysiol.* 1997 Sep; 37(6):365-78.

On a population of 52 subjects surface electromyographic recordings were performed of 13.5 sec. of duration before and after ULF (Ultra Low Frequency)-TENS relaxing procedure, while they were holding their mandible at rest. For each recording the average of tension (IEMG) and the median of frequency was calculated. To compute the median of frequencies a Fast Fourier Transformer (FFT) was applied. In order to compare modifications induced by the 45' ULF-TENS relaxing procedure, so that the influence of ULF-TENS could be well isolated from any influence due simply to the time passing between one recording and another, three recordings were performed at different times: the first at time 0', the second at time 0' + 20', and only the third after TENS, time 0' + 20' + 45'. The results of the study permit us to draw the following conclusions: 1. it is confirmed that ULF-TENS can decrease muscle IEMG; 2. the study of the IEMG and frequency of the electromyographic signal at rest can be carried out starting from a window whose size and position in the 13.5 sec. of recording is arbitrary; 3. there is no connection between IEMG and frequency: in other words, at rest, there is no necessary correspondence between high or low IEMG and a high or low frequency values; 4. on application of the neurodiagnostic test of ULF-TENS, the IEMG of the electromyographic signal decreases, while the frequency of the signal remains unchanged. These last two observations permit us to hypothesize that the IEMG and the frequency of the electromyographic signal reflect some different and independent characteristics of the electrical activity of the muscle at rest.

Eble, O.S., Jonas, I.E., and Kappert, H.F. Transcutaneous electrical nerve stimulation (TENS): its short-term and long-term effects on the masticatory muscles. *J. Orofac Orthop.* 2000; 61(2):100-11.

In an electromyographic study on subjects with no functional disturbances of the masticatory muscles, the duration of the post-therapeutic effects of transcutaneous electrical nerve stimulation (= TENS) on the superficial masseter and anterior temporal muscle was analyzed. The myoelectric signals were registered from 20 healthy volunteers in 3 different mandibular positions. The recordings were performed before a 20-minute TENS application with the J-4 Myomonitor and continued with a sequence of follow-up registrations with increasing interval to the initial stimulation. The EMG signals underwent computer-aided analysis and were evaluated by determining the integrated values as a parameter of muscle activity, and after Fourier transformation by 7 describing parameters of the power spectrum (e.g. mean power frequency = MPF). A detailed analysis of variance of all data was used to investigate significant changes of the parameters during the observation period. Muscular response to TENS includes a decrease in muscular activity (= reduction in integrated EMG signals) and a shift in the power spectrum to higher frequencies (increase in MPF). These changes were statistically highly significant for both analyzed muscles and for all different mandibular exercises. As these reactions to TENS are contrary to muscle fatigue, the results can be interpreted as indicating that this type of therapy stimulates a change in the biochemical and physiological muscular conditions, which leads to muscle relaxation.

Electromyographically, the post-therapeutic effect lasted for 2 hours in case of normal masticatory muscle activity but for more than 7 hours in case of low muscular loading. The alterations of the integrated EMG values were more persistent than those of the parameters of the power spectrum.

SECONDARY REFERENCES

[Low Frequency TENS Studies cited within the articles reviewed in this publication]

- Academy of Denture Prosthetists. Glossary of Prosthetic Terms. *J. Pros. Dent.*, 6:25, 1956.
- Akil, H., and Mayer, D.J. Antagonism of stimulation-produced analgesia by p-CPA, a serotonin synthesis inhibitor. *Brain Res.* 44:692-697, 1972.
- Algren, J. Mechanism of mastication. *Acta Odontol. Scand.*, 24: Supp. 44, 1-109, 1966.
- Algren, J., Ingervall, B. and Thilander, B. Muscle activity in normal and postnormal occlusion. *Am. J. Orthod.*, 64:445-456, 1973.
- Ailing, C.C., and Mahan, P.E. Facial pain. Lea & Febiger, Philadelphia; 1977.
- Almay, B.G.L., Johansson, F., von Knorring, L., Terenius, L., and Wahlstrom, A. Endorphins in chronic pain: I. differences in CSF endorphin levels between organic and psychogenic pain syndromes. *Pain*, 5:153-162, 1978.
- Andersson, S.A. Akupunktur for analgesi pa katt. En preliminar rapport. *Lakartidningen* 70:707-708, 1973.
- Andersson, S.A., Erickson, J., Holmgren, E., and Lindquist, G. Electroacupuncture and the pain threshold. *Lancet*, 2:564, 1973.
- Andersson, S.A., Erickson, J., Holmgren, E., and Lindquist, G. Electroacupuncture: Effect on pain threshold measured with electrical stimulation of teeth. *Brain Research*, 63:393-396, 1973.
- Andersson, S.A., and Holmgren, E. On acupuncture analgesia and the mechanism of pain. *Amer. J. Chin. Med.*, 3:311-334, 1975.
- Andersson, S.A., Ericson, T., Holmgren, E., and Lindquist, G. Analgesic effects of peripheral conditioning stimulation. I: General pain threshold effects on human teeth and a correlation to psychological factors. Submitted for publication; 1975a.
- Andersson, S.A., Holmgren, E., and Roos, A. Analgesic effects of peripheral conditioning stimulation. II: Importance of certain stimulation parameters. Submitted for publication; 1975b.
- Andersson, S.A., and Holmgren, E. Analgesic effects of peripheral conditioning stimulation. III: Effect of high frequency stimulation; segmental mechanisms interacting with pain. Submitted for publication; 1975c.
- Andersson, S.A., Block, F., and Holmgren, E. Lagfrekvent transkutan elektrisk stimulering for smartlindring vid forlossning. *Lakartidningen* 73(26-27); 2421-2423. In Swedish, summary in English; 1976.
- Andersson, S.A., and Holmgren, E. Pain threshold effects of peripheral conditioning stimulation. *Advances in Pain Research and Therapy*. ed. J.J. Bonica and D. Albe-Fessard, pp. 761-678, Raven Press, New York 1976.
- Andersson, S.A., Hansson, G., Holmgren, E., and Renberg, O. Effects of conditioning electrical stimulation on the perception of pain. *Acta ortop. Scand.* 47:149-162, 1976a.
- Andersson, S.A., Holmgren, E., and Roos, A. Analgesic effects of peripheral conditioning stimulation. *Acupunct. Electrother. Res.* In Press 1976b.
- Andersson, S.A. Ericson, T., Holmgren, E., and Lindquist, G. Analgesic effects of peripheral conditioning stimulation. I: General pain threshold effect on human teeth and correlation to psychological factors. *Acupuncture & Electro-Therapeut. Res. mt. J.* 2:307-322, 1977a.
- Andersson, S.A., Holmgren, E., and Roos, A. Analgesic effects of peripheral conditioning stimulation. II: Importance of certain stimulation parameters. *Acupuncture & Electro-Therapeut. Res. mt. i.* 2:237-246, 1977c.
- Andersson, S.A. Pain control by sensory stimulation. In: J.J. Bonica et. al. Eds., *Advances in pain research and therapy*, vol. 3. pp 569-585, New York, Raven Press; 1979,

- Andersson, S.A. Augustinsson, L.E., Carlsson, C.A., Holmgren, E., Lund, S., and Roupe G. Afferents involved in the relief of itch and pain during transcutaneous electrical stimulation. In preparation, 1979.
- Anthony, M. Relief of facial pain. *Drugs* 18:122-129, 1974(?).
- Apfelbaum, R.I. A comparison of percutaneous radio frequency trigeminal neurolysis and microvascular decompression of the trigeminal nerve for the treatment of tic douloureux. *Neurosurgery*, 1:16-21, 1977.
- Astrom, K.E. On the central course of afferent fibres in the trigeminal, facial, glossopharyngeal, and vagal nerves and their nuclei in the Mouse. *Acta Physiol Scand.* 29 (suppi 106) pp 209-320; 1953.
- Augustinsson, L.E., Bohlin, P., Bundsen, P., Carlsson, C.A., Forssman, L., Sjoberg, P., and Tyreman, N.O. Pain relief during delivery by transcutaneous electrical nerve stimulation. *Pain*, 4:59-65, 1977.
- Azarbal, M. Comparison of myo-monitor centric position to centric relation and centric occlusion. *J. Prosthet. Dent.* 38:3, 331 -337, 1977.
- Balagura, S., and Ralph, T. The analgesic effect of electrical stimulation of the diencephalon and mesencephalon. *Brain Res.* 60:369-379, 1973.
- Basmajian, J.V. *Muscle alive*. Williams and Wilkins, Baltimore, MD; 1978.
- Bazzoti, L. *Manuale Pratico di Kinesiologic Centro ricerche scientifiche applicate ologolatrico ed Ortodontico*, Milan, Oct. 15, 1983.
- Bessette, R.W., and Quinlivan, J.T. Electromyographic evaluation of the Myo-Monitor. *J. Prosthet. Dent.* 30:19-24, 1973.
- Besson, J.M., Wyon-Maillard, M.C., Benoist, J.M., Conseiller, C., and Hamann, K. Effects of phenoperidine on lamina v cells in the cat dorsal horn. *J. Pharmaca (?) Exp. Ther.*, 187:239-245, 1973.
- Biglund, B. and Lippold O.C.J. *J. Physiol*, 123:214-224, 1954.
- Bonde-Petersen, F., and Christensen, L.V. Blood flow in human temporal muscle during tooth grinding and clenching as measured by ¹³³Xenon clearance. *Scand. J. Den. Res.* 81:272-275, 1973.
- Bratzlavsky, M. Human brainstem reflexes. In: M. Shahani Ed., *The motor system: neurophysiology and muscle mechanism*, Section IV, pp. 135-154, Amsterdam, Oxford, New York, Elsevier Scientific Publishing Co.; 1976.
- Brill, N., Schubeler, S., and Tryde, G. Influence of occlusional patterns on movements of the mandible. *J. Prosthet. Dent.*, 12:255-261, 1962.
- Buchthal, F., Guld, C., and Rosenfalck, P. Propagation velocity in electrically activated muscle fibres in man. *Acta Physiologica Scand.* 34:75, 1955.
- Burton, R. The problem of facial pain. *J. Am. Dent. Assoc.* 79:93, 1969.
- Carlsoo, S. Motor units and action potentials in masticatory muscles. *Acta Morphologica Neerlandica -Scand.* 2:13, 1958.
- Carlsson, G. Neuromuscular Problems in Orofacial Region. *mt. Dent. J.*, Sept. 30, 1981.
- Chaco, J. Electromyography of the masseter muscles in Costen's syndrome. *J. Oral Med.*, 28:45-46, 1973.
- Chaffin, B. *J Occup Med* 11:109-115, 1969.
- Chapman, C.R., Gehrig, J.D., and Wilson, M.E. Acupuncture compared with 33 percent nitrous oxide for dental analgesia. *Anesthesiology*, 42:532-537, 1975.
- Chapman, C.R., Wilson, M.E., and Gehrig, J.D. Comparative effects of acupuncture and transcutaneous stimulation on the perception of painful dental stimuli. *Pain*, 2:265-283, 1976.
- Chiang, C., Chang, C., Chu, H., and Yang, L. Peripheral afferent pathway for acupuncture analgesia. *Sci. Sinica.*, 16:210-217, 1973.

- Choi, B.B., and Mitani, H. On the mandibular position regulated by MyoMonitor stimulation. *J. Jap. Prosth. Soc.* 17:79-96, 1973.
- Christensen, L.V. Eksperimentelt provokerede ansigtssmerter fra kaebernes bevaegesystem ved bruxisme. *Tandlaegebladet* 71:1171-1181, 1967.
- Christensen, L.V. Facial pain from experimental tooth clenching: A preliminary report. *Tandlaegebladet* 74:175-182, 1970.
- Christensen, L.V., *J. Oral Rehab.* 6:119-136, 1979.
- Cooper, S. Muscle spindles and other muscle receptors. In: G.H. Bourne Ed., *The structure and function of muscle*, pp. 381-420, New York, Academic Press, 1960.
- Dandy, W.E. Concerning the cause of trigeminal neuralgia. *Am. J. Surg.*, 24:447-455, 1934.
- Dahlstrom, A. and Fuxe, K. Evidence for the existence of monamine neurons in the central nervous system. II. Experimentally induced changes in the intraneuronal amine levels of bulbospinal neuron systems. *Acta physiol. Scand.* 64, Suppl. 247, 1-36, 1965.
- Dao, T.T.T., Feine, J.S., and Lund, J.P. Can electrical stimulation be used to establish a physiologic occlusal position? *3 Prosth Dent*, 60(4):509-514, 1988.
- Dawson, G.D., and Merton, P.A. 'Recurrent' discharges from motoneurons. 20th International Congress of Physiology, Brussels, (Abstracts of communication) p 221, 1956.
- DeBiasi, S. and Neironi, P. Analisi Kinesiografica ed Elettromiografica dei muscoli Masticatori nella sindrome di Moebius. *Rivista kaliana di Stomalogia* 11, 1982.
- De Boever, J., and McCall, W.D. Physiological aspects of masticatory muscle stimulation: The Myo-Monitor. *Quintessence mt.* 3:57-58, 1972.
- De Steno, C.V. The pathophysiology of TMJ dysfunction and related pain. *Clinical Management of Head, Neck and TMJ Pain Dysfunction*, W.B. Saunders Co., Philadelphia, 1977.
- Derijk, W.G., Jones, G.L., and Keith, K.D. *J. Dent Res*, 56, Abs. 193, 1977.
- Dinham, R. Treatment of tic douloureux with Jankelson Myo-Monitor. *J. Hawaii Dent. Assoc.*, vol. III, 1970.
- Dixon, H.H., O'Hara, M. and Peterson, R.D. Fatigue contracture of skeletal muscle. *Northwest Med.* 66:813, 1967.
- Dixon, H.H., Davenport, H.A., and Ranson, S.W. Chemical studies of muscle contracture. II. The distribution of phosphorus in frog muscle during delayed relaxation. *J. Biol. Chem.*, 82:61-70, (April) 1929.
- Dixon, H.H. and Ranson, S.W. Elasticity and permanent deformation of muscle when stretched by moderate loads. *Anat Rec* 35:9-10, (March) 1927.
- Dixon, H.H., Peterson, R.D., Dickel, H.A., et al. High energy phosphates in the muscles of depressed and fatigued patients. *West J Surg* 60:327-330, (July) 1952.
- Dorpat, T.L. Mechanisms of muscle pain. Thesis University of Washington. *Neurophysiology*, (Edited: Ruth, T.C., Patton, H.D., Woodbury, J.W. and Towe, A.L.) Saunders, Philadelphia; pp 350-352; 1952.
- Duggan, A.W., Hall, J.G., and Headly, P.M. Morphine, enkephalin and the substantiagelatinosa. *Nature*, 264:456-458, 1976.
- Eccles, J.C. and O'Connor, W.J. Responses which nerve impulses evoke in mammalian striated muscles. *J. of Physiology*, 97:44, 1939.
- Edwards, R.G. and Lippold, O.C.J. *J. Physiol*, 132: 677-681, 1956.
- Elzack, R., Dennis, S.G. Pain mechanisms: theoretical approaches. In: R.F. Beers, Jr., and E.G. Bassett Eds., *Mechanisms of pain and analgesic compounds*, pp. 185-193, New York, Raven Press; 1979.

- Enomoto, T., Fukuoka, K., Imai, Y., Kako, M., Kaneko, Y., Mishimagi, M., Quo, A. and Dubota, K. Masseteric monosynaptic reflex in chronic cat. *Japanese J. of Physiology*, 18:169, 1968.
- Eriksson, M., and Sjolund, B. Acupuncture-like electroanalgesia in TNS resistant chronic pain. *Sensory Functions of the Skin*, ed. Y. Zotterman, pp 575-581. Oxford University Press, New York, 1976.
- Enberg, I., Lundberg, A., and Ryall, R.W. Reticulospinal inhibition of transmission in reflex pathways. *J. Physiol.*, 194:201-223, 1968a.
- Enberg, I., Lundberg, A., and Ryall, R.W. Reticulospinal inhibition of interneurons. *J. Physiol.* 194:225-236, 1968b.
- Enberg, I., Lundberg, A., and Ryall, R.W. The effect of Preserpine on transmission in the spinal cord. *Acta physiol. Scand.* 72:115-122, 1968c.
- Enberg, I., Lundberg, A., and Ryall, R.W. Is the tonic decerebrate inhibition of reflex paths mediated by monoaminergic pathways? *Acta physiol. Scand.* 72:123-133, 1968d.
- Enomoto, T., et al. Masseteric monosynaptic reflex in chronic cat. *Jap. J. Physiol* 18:169-178, 1968.
- Eriksson, M. and Sjolund, B. Acupuncture-like electroanalgesia in TNS resistant chronic pain. *Sensory Functions of the Skin* Ed. Y. Zotterman pp. 575-581, 1976.
- Eriksson, M.B.E., Sjolund, B.H., Nielzen, S. Long term results of peripheral conditioning stimulation as an analgesic measure in chronic pain. *Pain*, 6:335-347, 1979.
- Erb, W. *Handbook of electrotherapeutic*, New York, William Wood, 1883.
- Farrar, W.B. The TMJ dilemma. *J. Alabama Dent. Assoc.*, 63:19-26, 1979.
- Farrar, W.B., and McCarty, W.L., Jr. Inferior joint space arethrography and characteristics of condylar paths in internal derangements of the TMJ. *J. Prosthet. Dent.* 41:548, 1979.
- Fields, H.L., and Basbaum, A.I. Brainstem control of spinal pain- transmission neurones. *Annu. Rev. Physiol.*, 40:217-248, 1978.
- Fra, L. and Brignolio, F. F and H responses elicited from muscle of the lower limb in normal subjects. *J. of the Newrological Sciences*, 7:251, 1968.
- Freimann, R. Untersuchung uber Zahi und Anordnung der Muskeispindein in der Kanmuskein des Menschen. *Anat. Anz.*, 100:258-264, 1954.
- Fujii, H., and Mitani, H. Reflex responses of the masseter and temporal muscles in Man. *Journal of Dental Research*, 52:1046-1050, 1973.
- Funakoshi, M., Fujita, N., and Takehana, S. Relations between occlusal interference and jaw muscle activities in response to changes in head position. *J. Dent. Res.*, 55:684-690, 1976.
- Ganong, W.F. *Review of medical physiology* 5th edn. p. 34 Maruzen (Asian edn.) Tokyo. 1971.
- Gasser, H.S., and Grundfest, H. Axon diameters in relation to the spike dimensions and the conduction velocity in mammalian A fibres. *American J. of Physiology*, 127:393, 1939.
- Gaw, A.C., Chang, L.W., and Shaw, L.C. Efficacy of acupuncture on osteoarthritic pain. *New Engl. J. Med.* 293, 375-378, 1975.
- Gelb, H. et al. *Clinical management of head, neck, and TMJ pain and dysfunction*. W.B. Saunders Co., Philadelphia, 1978.
- George, J.P., and Boone, M.E. A clinical study of rest position using the Kinesiograph and Myo-Monitor. *J. Prosthet. Dent.* 41:456, 1979.
- Gernet, W. et al. Use of the Myo-monitor in the functionally disturbed system. *Deutsche Zahnartzliche Zeitschrift*, 35(6), Eng. Abstract, German J., June 1980.

- Goodgold, J., and Ritchie, A.E. Clinical electromyography. Philadelphia, J.B. Lippincott Company, pp 7, 42, 56, 62, 65, 1973.
- Goodwill, C.J. The normal jaw reflex: Measurement of the action potential in the masseter muscles, *Annals of Physical Medicine*, 9:183, 1968.
- Graber, T.M. Orthodontics, principles and practices. p. 146, Philadelphia; W.B. Saunders; 1961.
- Gregg, J.M. Post-traumatic trigeminal neuralgia: response to physiologic, surgical and pharmacologic Therapies. (?) *Dent. J.*, 28:43-51, 1978.
- Gregg, J.M., Grady, J.D. Posttraumatic sensory disorders (?) 7th Trigeminal System. *J. Dent. Res.*, 54A:165, 1975 (Abstract).
- Grosfeld, O. Changes of muscle activity patterns as a result of orthodontic treatment. *Tr. Eur. Orthod. Soc.*, 41:203-214, 1965.
- Hannam, A.G. Effects of voluntary contraction of the masseter and other muscles upon the masseteric reflex in man. *Journal of Neurology, Neurosurgery and Psychiatry*, 35:66-71, 1972.
- Harris, R. Chronaxy. *Electrodiagnosis and electromyography*, ed. 3, New Haven, Conn., Elixabeth Licht, pp. 229, 1971.
- Harrison, F., and Corbin, K.B. The central pathway for the jaw-jerk. *American Journal of Physiology*, 135:439, 1942.
- Hodos, W. Nonparametric index of response bias for use in detection and recognition experiments. *Psychol. Bull.*, 74:351-354, 1970.
- Holmdahl, M.H.son. Bedovningseffekter av akupunktur. *Lakartidningen* 70:701-720, 1973.
- Holmgren, E. Effects of Conditioning Electrical Stimulation on the Perception of Pain. Doctoral Thesis, Dept. of Physiology, University of Goteborg, Goteborg, Sweden, 1975.
- Holmgren, E. Increase of pain threshold as a function of conditioning electrical stimulation. *Am. J. Chin. Med.* 3:133-142, 1975.
- Holmquist, B., Lundberg, A., and Oscarsson, O. Supraspinal inhibitory control of transmission to three ascending spinal pathways influenced by the flexion reflex afferents. *Arch. Ital. Biol.* 98:60-80, 1960.
- Homma, S. On Evoked Electromyogram in Human Body. *Medicine of Japan in 1959*, 5:399-407 (Japanese); 1959.
- Horisberger, B., and Rodbard, S. Relation between pain and fatigue in contracting ischemic muscle. *Am. J. Cardiol.* 8:481-484, 1961.
- Hua Shan Hospital of Shanghai First Medical College, Shanghai. Observations on analgesic effect of needleling chuanliao point in neurosurgery. Report of 619 cases. *Chin. Med. J.* 2:16, 1973. Abstract in English.
- Hugelin, A., and Bonvallet, M. Etude Electrophysiologique d'un reflexe monosynaptique trigeminal, *C R. Soc. Biol (Paris)* 150:2067-2071, 1959.
- Hughes, J., Smith, T.W., Kosterlitz, H.W., Fothergill, L.A., Morgan, B.A., and Morris, H.R. Identification of two related pentapeptides from the brain with potent opiate agonist activity. *Nature* 258:577-579 (Lond.) 1975.
- Hymes, A., Yonehiro, E.G., Raab, D.E., et al. Electrical surface stimulation for treatment and prevention of ileus and atelectasis. *Surg. Forum*, 25:222-224, 1974.
- Hymes, A.C., Raab, D.E., Yonehiro, E.G., Nelson, G.D. and Printy, A.L. Acute pain control by electrostimulation: A preliminary report. *Adv. Neurol.*, 4:761-767, 1974.
- Ihalainen, J., Perkki, K. The effect of Transcutaneous Nerve Stimulation (TNS) on chronic facial pain. *Proc. Finn. Dent. Soc.*, 74:86-90, 1978.
- Inman, V.T., Ralston, H.J., Saunders, J.B., and Feinstein, B. *EEG Clin Neurophysiol*, 4:187-194, 1952.

- Jankelson, B. Myo-Monitor. An electronic, extra-oral system delivering unequaled precision in the registration of occlusion. Myo-tronics; 1971.
- Jankelson, B. As quoted in Jankelson, J. Prosth Dent, pp 1973; 1969.
- Jankelson, B., and Swain, C.W. Physiological aspects of masticatory muscle stimulation: The Myo-Monitor (A Critique of). Quintessence International, 3:12, 57-62, 1972.
- Jach, E.T. Miniclinic - The Jankelson Myo-monitor. Chicago Dental Society Review, 1974.
- Jankelson, B. Functional positions of occlusion. J. Prosthet. Dent. 30:559, 1973.
- Jankelson, B. Neural conduction of the Myomonitor stimulus: A quantitative analysis. J. Prosthet. Dent. 34:3, 1975.
- Jankelson, B., Swain, C.W., Crane, P.F., and Radke, J.C. Kinesiometric instrumentation: A new technology. J. Am. Dent. Assoc. 90:834-840, 1975.
- Jankelson, B., Sparks, S., and Crane, P.F. Neural conduction of the Myomonitor stimulus: A quantitative analysis. J. Prosthet. Dent. 34:245 - 253, 1975. V
- Jankelson, B. Research and diagnostic applications of the mandibular kinesiograph. Unpublished. Myo-tronics Research, Inc., Seattle, 1976.
- Jankelson, B., and Radke, J.C. The Myo-monitor: Its use and abuse (I). Quintessence International, 9:35-39, 1978 9:47-52, 1978.
- Jankelson, B. Neuromuscular aspects of occlusion. Dent. Clin. North Am. 23:157, 1979.
- Jankelson, B. Neuromuscular technology for complete dentures. In Proceedings of the Second International Prosthodontic Congress, St. Louis, The C.V. Mosby Co.; 1979.
- Jankelson, B. Research findings and resultant management of craniomandibular (TMJ) symptom cluster syndrome. In Proceedings of the Second International Prosthodontic Congress, St. Louis.; The C.V. Mosby Co.; 1979.
- Jankelson, B. Research findings and resultant management of craniomandibular (TMJ) symptom cluster syndrome. Proceedings of the 2nd International Prosthodontic Congress, W. Lefkowitz Ed., St. Louis, Toronto, London, C.V. Mosby Co.; 1979.
- Jankelson, B. A manual - The Myo-Tronic orthopedic splint. Seattle, WA; Myo - Tronics Research, Inc.; 1980.
- Jankelson, B. Measurement accuracy of the Mandibular Kinesiograph: A computerized study. J. Prosthet. Dent. 44:656, 1980.
- Jankelson, B. The effect of the Myo-Monitor on relaxation of the craniomandibular musculature. Unpublished manuscript, 1981.
- Jankelson, B. Modern diagnosis and management of musculoskeletal dysfunction of the head and neck. Diseases of the Temporomandibular Apparatus, Morgan et al., 2nd ed., C.V. Mosby Co., St. Louis; 1982.
- Jannetta, P.J. Neurovascular compression in cranial (nerve?) and systemic disease. Ann. Surg., 192:518-525, 1980.
- Jerge, C.R. Organization and function of the trigeminal mesencephalic nucleus. J. Neurophysiol, 26:379-392, 1953.
- Johnson, E.W. Electromyographic Examination. Electrodiagnosis and electromyography, ed. 3, New Haven, Conn., Elizabeth Licht., 1971.
- Kaada, B. Noel, E., Leseth, K., Nygaard-Ostby, B., Setekleiv, J., and Stovner, J. Acupuncture analgesia in the People's Republic of China. T. Norske Laegeforen. 94:417-442, 1974.
- Katz, B. and Miledi, R. The measurement of synaptic delay, and the time course of acetylcholine release at neuromuscular junction. Proceedings of the Royal Society of London, Series B., V, 161, 483, 1965.

- Kawamura, Y. Recent concepts of the physiology of mastication. *Advances of Oral Biology*, New York, Academic Press. ed. Staple, P.H. pp 77-109; 1964.
- Kawamura, Y., Takata, M., and Miyoshi, K. The influence of pyriethoxin on the mandibular reflex system. *J. Osaka Univ. Dent. School*, 9:139-147, 1969.
- Kissin, M. The production of pain in exercising skeletal muscle during induced anoxia. *J. Clin. Invest.* 13:37-45, 1934.
- Kitahata, L.M., Kosaka, Y., Taub, A., Bonikos, K., and Hoffert, M. Lamina specific suppression of dorsal horn unit activity by morphine sulfate. *Anesthesiology*, 41:39-48, 1974.
- Kovacs, R. *Electrotherapy and light therapy*. 4th ed. chap. 9, p. 185; pub. Lea & Febiger; 1942.
- Kwatny, E., Thomas, D.H., and Kwatny, H.G. *I.E.E.E. Trans Biomed Engng*, 17:303-312, 1970.
- Kugelberg, E. Facial reflexes. *Brain*, 75:385, 1952.
- Laskin, D.M. Etiology of the pain-dysfunction syndrome. *J. Am Dent Ass.*, 79: 144, 148-153, 1969.
- Lamarre, Y., and Lund, J.P. Load compensation in human masseter muscles. *J. Physiol. (Lond.)*, 253:31 -35, 1975.
- LeBars, D., Menetrey, D. and Besson, J.M. Effects of morphine upon the lamina v type cells activity in the dorsal horn of the decerebrate cat. *Brain Res.*, 113:293-310, 1976.
- Lenman, J., and Ritchie, A.E. *Clinical electromyography*. Philadelphia, J. B. Lippincott Company, pp 7, 42, 56, 62, 65, 1973.
- Lewis, T. *Pain*. New York: Macmillan, 1942.
- Lewis, T., Pickering, W., and Rothchild, P. Observations upon muscular pain in intermittent claudication. *Heart* 14:359-383, 1931.
- Liebman, F.M. and Cosenza, F. An evaluation of electromyography in the study of the etiology of malocclusions. *J. Prosthet. Dent.*, 10:1065-1077, 1960.
- Lindblom, G. Disorders of the temporomandibular joint, causal factors and a value of temporomandibular radiographs in their diagnosis and therapy. *Acta Odontol. Scand.*, 11:61, 1953.
- Lindsstrom, I., and Hellsing, G. *Archs Oral Biol*, 28:297-301, 1983.
- Lippold, O.C.J. *J. Physiol*, 117:492-499, 1952.
- Loeser, J.D. The management of tic douloureux. *Pain*, 3:155-162, 1977.
- Loeser, J.D., Black, R.D., and Christman, A. Relief of pain by transcutaneous stimulation. *J. Neurosurg.*, 42:308-314, 1975.
- Long, D. Cutaneous afferent stimulation for relief of chronic pain. *Congr. Neurol. Surg.* 21:257-268, 1974.
- Long, D. The comparative efficacy of drugs vs. electrical modulation in the management of chronic pain. LeRoy PL (ed.) *Current Concepts in the Management of Chronic Pain*. Year Book Medical Publishers, Chicago, 1977.
- Long, D.M. Cutaneous afferent stimulation for the (?) of pain. *Prog. Neurol. Surg.*, 7:35-51, 1976.
- Long, D.M. and Hagfors, N. Electrical stimulation in the nervous system: The current status of electrical stimulation of the nervous system for relief of pain. *Pain*. 1:109-123, 1975.
- Lous, I., Sheikoleslam, A., and Moller, E. Postural activity in subjects with functional disorders of the chewing apparatus. *Scand. J. Dent. Res.* 78:404- 410, 1970.
- Lupton, D.E. Psychological aspects of temporomandibular joint dysfunction. *J. Am. Dent. Assoc.*, 79:131, 1969.
- Magladert, J.W. Some observations on spinal reflexes in man. *Pfluegers Arch.*, 261:302-321, 1955.

- Magora, F., Aladjemoff, L., and Tannenbaum, J., et al. Treatment of pain by Transcutaneous Electrical Stimulation. *Acta Anaesth. Scand.*, 22:589-592, 1978.
- Mann, F., Bowsher, D., Lipton, S., Mumford, J., and Miles, J. Treatment of intractable pain by acupuncture. *Lancet* 2:57-60, 1973.
- Mark, L. Double-blind Studies of Acupuncture. *J. Amer. Med. Ass.*, 225:1532, 1973.
- Martin, W.R. Opioid antagonists. *Pharmacol Rev.* 19:262-278, 1967.
- Mayer, D.J., Wolfle, T.L, Akil, H., Carder, B., and Liebeskind, J.C. Analgesia from electrical stimulation in the brainstem of the rat. *Science* 174:1351-1354, 1971.
- Mayer, D.J., and Price, D. D. Central nervous system mechanisms of analgesia. *Pain*, 2:379-404, 1976.
- Mayer, J.D., Price, D.D., and Rafii, A. Acupuncture hypalgesia: Evidence for activa...(?)of a central control system as a mechanism of action. 1st World Congress on Pain, Florence abstr. 276, 1975.
- Mayer, R.F., and Feldman, R.G. Observations on the nature of F wave in man. *Neurology (Minneapolis)*, 17:147, 1967.
- McArdle, B. Myopathy due to defect in muscle glycogen breakdown. *Clin. Sci.* 10:13-35, 1951.
- McBurney, D.H. Acupuncture, pain and Signal Detection Theory. *Science*, 189:66, 1975. References Page B-115
- McIntyre, A.K. Afferent Limb of the myotatic reflex arc. *Nature (London)*, 168:168-169, 1957.
- McIntyre, A.K., and Robinson, R.G. Pathway for the jaw-jerk in man. *Brain*, 82:468, 1959.
- McKenna, B.R., and Truder, K.S. *Arch Oral Biol*, 23:917-920, 1978.
- Meizack, R. and Wall, P. Pain mechanisms: A new theory. *Science* 150:971, 1965.
- Meizack, R., and Melinkoff, D.F. Analgesia produced by stimulation: Evidence of a prolonged onset period. *Exp Neurol.* 43:369-374, 1974.
- Merton, P.A. *J Physiol (London)*, 123:553-564, 1954.
- Mikhail, M. and Rosen, H. History and etiology of M.P.D. *J. Pros. Dent.* 44:438, 1969.
- Miki I., and Tokizane, T. *Kindenzu Nyamom*, 3rd ed., p. 19. Nanzando, Tokyo; 1967.
- Miller, E. Evidence that the rest position is subject to serv-control. DJ. Anderson and B. Mathews Eds., *Mastication*, Bristol, Wright and Sons; 1975.
- Miller, E., Rasmussen, O.C., and Bonde-Petersen, F. Mechanism of ischemic pain in human muscles of mastication: Intramuscular pressure, EMG, force and blood flow of the temporal and masseter muscles during biting. In: J.J. Bonica et al. Eds., *Advances in pain research and therapy*, 3:271-281, New York, Raven Press; 1979.
- Milner-Brown, H.S., and Stein R.B. 246: 549-569, 1975.
- Moller E. The chewing apparatus. An electromyographic study of the action of the muscles of mastication and its correlation to facial morphology. *Acta Physiol. Scand.* 69 suppl. 280; 1966.
- Moller, E. Action of the muscles of mastication. *Physiology of Mastication* (Edited by Kawamura, Y) pp. 121-158, Karger, Basel; 1974.
- Mortimer, J.T., Magnusson, R., and Petersen, I. *Am J Physiol* 219:1324-1329; 1970.
- Moss, J.P. and Greenfield, B.E. An electromyographic investigation and survey of Class II cases. *Tr. Br. Soc. Study Orthod.*, pp 147-156; 1965.
- Moss, J.P. and Chalmers, C.P. An electromyographic investigation of patients with normal jaw relationship and a Class HI jaw relationship. *Am. J. Orthod.*, 66:538-556, 1974.

- Moss, J.P. Function-facts or fiction? *Am. Orthod.*, 67:625-646, 1975.
- Moyers, R.E. Temporomandibular muscle contraction patterns in Angle Class H, Division 1 malocclusions: An electromyographic analysis. *Am. J. Orthod.*, 35:837-857, 1949.
- Munro, R.R., and Griffin, C.I. Electromyograph of the jaw jerk recorded from the masseter and anterior temporalis muscles in man. *Archives of Oral Biology*, 16:59, 1971.
- Myhaug, H. Objektiver nachweis von parafunktionen der inenohrmuskulatur. *Parodontologie*, 12:107-112, 1971.
- Myo-Monitor Instruction Manual Myo-tronics Research, Inc., Seattle, WA; 1971.
- Myo-Monitor Instruction Manual Myo-tronics Research, Inc., Seattle, WA; 1974.
- Myo-Monitor Instruction Manual Myo-tronics Research, Inc., Seattle, WA; 1976.
- Myo-Monitor Instruction Manual Myo-tronics Research, Inc., Seattle, WA; 1977.
- Neilson, D.P., Andrews, G., Guitar, B.E., and Quinn, P.T. Tonic stretch reflexes in lip, tongue and jaw muscles. *Brain Res.*, 178:311-327, 1979.
- Neilzen, S., Sjolund, B.H., and Eriksson, M.B.E. Psychiatric factors influencing the treatment of pain with peripheral conditioning stimulation. *Pain*, 13:365-371, 1982.
- Nordstrom and Yemm, *Archs Oral Biol*, 19:353-359, 1974.
- Oester, Y.T., and Light, S. Routine electrodiagnosis. *Electrodiagnosis and Electromyography* ed. 3, New Haven, Conn., Elizabeth Licht, p 206, 1971.
- Oliveras, J.L., Besson, J.M., Guilbaud, O., and Liebeskind, J.C. Behavioral and electrophysiological evidence of pain inhibition from midbrain stimulation in the cat. *Exp. Brain Res.* 20:32-44, 1974.
- Oliveras, J.L., Woda, A., Guilbaud, G., and Besson, J.M. Neurophysiologie - Effects analgesiants de la stimulation de la substance grise periaqueducule sur le reflexe d'ouverture de la gueule declenche par stimulation de la pulpe dentaire chex le Chage eveille, libre de ses mouvements. *C.R. Acad. Sci Paris*, t. 276, 1973.
- Omura, Y. The effects of acupuncture on the nervous system: studies on threshold stimulation and conduction velocities of motor and sensory nerve fibers. Abstracts of the Third World Cong. of Acupuncture pp 209-210 Seoul, South Koria, September 25-27, 1973.
- Omura, Y. Pathophysiology of acupuncture treatment: effects of acupuncture on cardiovascular and nervous system. *Acupuncture & Electro-Therapeut. Res. hit. J.* 1:51-141, 1975.
- Omura, Y. Electro - Acupuncture: Its electro-physiological basis and criteria for effectiveness and safety - Part I. *Acupuncture & Electro-Therapeutics Res.* 1:157-181, 1975.
- Ota, Y. Personal communication. 1971.
- Ott, K., and Winkimair, M. Zur anwendung des Myo-monitor fur die relationsbetimmung. *Dtsch. Zahnarzl. Z.* 32:594-598, 1977.
- Ottoson, D., Ekblom, A., and Hansson, P. Vibratory stimulation for the relief of pain of dental origin. *Pain.* 10:37-45, 1981.
- Palla, S. and Ash, M.M. *Archs Oral Biol*, 26:547-553, 1981.
- Pancherz, H. Activity of the temporal and masseter muscles in Class H, Division I malocclusions. *Am. J. Orthod.*, 77:679-688, 1980.
- Pantaleo, T., Prayer-Galletti, F., Pini Prato, G. Physiological mechanism underlying jaw muscles relaxation in the mandibular rest position. 2nd mt. Congress mt. College of Cranio-mandibular Orthopedics. Florence, Sept 29th-Oct. 1, Abstracts book, p. 25; 1980.
- Park, S.R., and Rodbard, S. Effects of load and duration of tension on pain induced by muscular contraction. *Am. J. Physiol.* 203:735-738, 1962.

- Paillard, J. Analysis electrophysiologique et comparaison chez l'Homme du reflexe de Hoffmann et du reflexe myotatique. *Pfluegers Archiv fur die Gesamte Physiologic des Menschen und der Tiere*. 260, 448; 1955.
- Peking Acupuncture Anaesthesia Co-ordinating Group: Preliminary study on the mechanism of acupuncture anaesthesia. *Scientia Sins*. 16:447-456, 1973.
- Pert, C.B., Taylor, D.P., and Pert A. J. of *Pharmacol. and Exp. Therap.* 154(2), 319-323, 1966.
- Picaza, J.A., Cannow, B.W., Hunter, S.E., Boyd, A.S., Guma, J. and Maurer, D. Pain suppression by peripheral nerve stimulation. *Surg. Neurol.* 4:105-114, 1975.
- Piper, H. *Electrophysiologie Menschlicher Muskein* Verlag von Julius Springer, Berlin. 1912.
- Pomeranz, B. and Chiu, D. Naloxone blockade of acupuncture analgesia: endorphin implicated. *Life Sci.* 19:1757-1762, 1976.
- Principato, J.J. Prefabricated Diagnostic Occlusal Devices of Temporomandibular Joint Dysfunction. Presentation to Am. Acad. Otolaryngology, New Orleans, Oct. 20, 1982.
- Ramfjord, S.P., and Ash, M.M., Jr. *Occlusion*, ed. 2, Saunders Philadelphia; 1971.
- Ranson, S.W. and Dixon, H.H. Contractures caused by tenotomy and by tetanus toxin. *Proc Soc Exp Biol Med* 24:725 (April) 1927.
- Ranson, S.W. and Dixon, H.H. Elasticity and ductility of muscle in myostatic contracture caused by tetanus toxin, *Am J. Physiol.* 86:312-319 (September) 1929.
- Rasmussen, P. *Facial pain: A clinical study with special reference to the symptomatology, aetiology and surgical therapy.* Copenhagen: Munksgaard, 1965, pp 1-353.
- Report on the findings and recommendations on transcutaneous electrical nerve stimulation for pain relief by the panel on review of neurological devices. Food and Drug Administration, 1976.
- Research Group of Acupuncture Anesthesia, Peking Medical College. Effect of acupuncture on pain threshold of human skin. *Chin. Med. J.*, 3:151-157, 1973.
- Rodbard, S., and Pragay E.B. Contraction frequency, blood supply, and muscle pain. *J. appl. Physiol.* 24:142-145, 1968.
- Rosenbert, M., Curtis, L. and Bourke, D.L. Transcutaneous electrical nerve stimulation for the relief of postoperative pain. *Pain.* 5:129-133, 1978.
- Roth, R.H. Temporomandibular pain dysfunction and occlusal relationships. *Angle Orthod.* 43:137, 1973.
- Rushton, J.G., Gibilisco, J.A., and Goldstein, N.P. Atypical Facial Pain. *JAMA*, 171:545-548, 1959.
- Scott, D.S., and Lundeen, T.F. *Pain*, 8:207-215, 1980.
- Schwartz, L. Pain associated with the temporomandibular joint. *J. Am. Dent. Assoc.*, 51:394, 1955.
- Schwartz, L. *Disorders of the temporomandibular joint.* Philadelphia, W.B. Saunders Co.; 1959.
- Schweizer, Hans. *Der Myomonitor.* Schweiz, Mschr. Zahnheilk, 81:12, 1187- 1194, 1971.
- Section of Thoracic Surgery of Peking Acupuncture Anesthesia Coordinating Group: Acupuncture anesthesia in thoracic surgery, clinical analysis of 818 cases. *Chin. Med. J.* 2:20, 1973, Abstract in English.
- Shafer, W.G., Hine, M.K., and Levy, B.M. *A textbook of oral pathology.* 3rd ed. Philadelphia, W.B. Saunders Co., pp. 26-27; 1974.
- Shanghai First People's Hospital, Shanghai. Acupuncture anesthesia in thyroidectomy. *Chin. Med. J.* 2:17, 1973, Abstract in English.
- Shapiro, H.H. *Maxillofacial anatomy with practical applications* p. 331. Lippincott, Philadelphia; 1954.

- Shealy, C.N. Transcutaneous electroanalgesia. *Surg. Forum*, 23:419-421, 1972.
- Shealy, C.N. Transcutaneous electrical stimulation for control of pain. *Clin. Neurosurg.*, 21:269-277, 1974.
- Sherrington, C.S. Reflexes elicitable in the cat from pinna vibrissae and jaws. *J. Physiol.* 51:404-431, 1917.
- Sjolund, B., and Eriksson, M. Electro-acupuncture and endogenous morphines. *Lancet*, 2:1085, 1976.
- Sjolund, B., Terenius, L., and Eriksson, M. Increased cerebrospinal fluid levels of endorphins after electro-acupuncture. *Acta Physiol. Scand.*, 100:382-384, 1977.
- Sjolund, B.H., and Eriksson, M.B.E. The influence of naloxone on analgesia produced by peripheral conditioning stimulation. *Brain Res.*, 173:295-301, 1979.
- Sjolund, B., and Eriksson, M. Endorphins and analgesia produced by peripheral conditioning stimulation. *Adv. Pain Res. Ther.*, 3:587-591, 1979.
- Stalberg, E. Propagation velocity in human muscle fibres. *Situ. Acta Physiologica Scandinavica.*, 70, Suppi, 287,1; 1966.
- Stephens, L.A., and Taylor, A. *J. Physiol (Lond)*, 220:1-18, 1972.
- Sutcher, H., et al. Comparison of responses to pharmacological and physical placebo therapy in TMJ dysfunction patients. *IADR Abstracts*. p. 243; 1966.
- Szentagothai, J. Anatomical considerations of monosynaptic reflex arcs. *J. Neurophysiol*, 11:445-454, 1942.
- Tei, K. Evoked EMG potentials as modified by voluntary contraction. *Journal of Juzen Medical Society*, 67, 65; 1961.
- 3M:TENS: How it works and when to use it. St. Paul, MN, 3M Corporation, 1963.
- Terenius, L., and Wahlstrom, A. Search for an endogenous ligand for the opiate receptor. *Acta Physiol Scand.* 94:74-81, 1975a.
- Terenius, L and Wahlstrom, A. Morphine-like ligand for opiate receptors in human CSF. *Life Sci.* 16:1759-1764, 1975b.
- Terenius, L., Wahlstrom, A., Lindstrom, L., and Widerlof, E. Increased CSF levels of endorphins in chronic psychosis. *Neurosci. Lett.* 3:157-162, 1976.
- Thomas, L.J., Tiber, N., and Schireson, S. The effects of anxiety and frustration on muscular tensions related to the temporomandibular joint syndrome. *Oral. Surg.*, 36:763-768, 1973.
- Thompsan, J.R. Temporomandibular disorders: Diagnosis and treatment. *The Temporomandibular Joint*, B.G. Sarnat, ed. p. 123, Springfield, IL: Charles C. Thomas; 1951.
- Thomson, H. Mandibular dysfunction syndrome. *Brit. Dent. J.* 130-187, 1971.
- Thorsteinsson, G., Stonnington, H.H., Stillwell, G.K. and Elveback, L.R. The placebo effect of transcutaneous electrical stimulation. *Pain.* 5:31- 41, 1978.
- Thorsteinsson, G., Stonnington, H.H., Stillwell, G.K., et al. Transcutaneous electrical stimulation: A double-blind trial of its efficacy for pain. *Arch. Phys. Med. Rehabil.* 58:8-13, 1977.
- Travell, J.G., and Simons, D.G. Myofascial pain and dysfunction: The trigger point manual. Baltimore: The Williams and Wilkin Co., pp. 273-281, 1983.
- Trott, P.H., and Goss, A.H. Physiotherapy in diagnosis and treatment of the myofacial-pain dysfunction syndrome. *mt J. Oral Surg.* 7:360, 1978.
- Van der Ark, G.D. and McGrath, K.A. transcutaneous electrical stimulation in treatment of postoperative pain. *Amer. J. Surg.* 130:338-340, 1975.

- Vesanen, E., and Vesanen, R. The Jankelson Myo-monitor and its clinical use. *Proc. Finnish Dent. Soc.* 69:244-247, 1973.
- Viitasalo, J.T., and Komi, P.V. *Electromyogr. Clin. Neurophysiol.* 18:167-178, 1978,
- Vitti, M. and Basmajian, J.V. Muscles of mastication in small children: An electromyographic analysis. *Am. J. Orthod.*, 68:412-419, 1975.
- Vitti, M. and Basmajian, J.V. Integrated actions of masticatory muscles: Simultaneous EMG from eight intramuscular electrodes. *Anat. Rec.*, 187:173-189, 1977.
- Voss, H. Em besonderes reichliches vorkommen von muskelspindel in der tief en portion des m. masseter des menschen und der anthropoiden. *Anat. Anz.*, 81:290-292, 1935.
- Vrendenbregt, J. and Rau, O. New developments in EMG and clinical neurophysiology, 1:607-622, 1973.
- Wahlstrom, A., Johansson, L., and Terenius, L. Characterization of endorphins (endogenous morphine-like factors) in human CSF and brain extracts. *Opiates and Endogenous Peptides* pp. 49-56 Ed. H.W. Kosterlitz North-Holland, Amsterdam, New York, Oxford, 1976.
- Wall, P.D., and Sweet, W.H. Temporary abolition of pain in man. *Science*, 155:108-109, 1967.
- Watkins, A.L. *A manual of electrotherapy.* Philadelphia, Lea & Febiger, Publishers, pp 141, 166, 1968.
- Weiss, M.H. Case report: Successful treatment of Bell's Palsy. *Dent Surv.*, Aug, 1976.
- Wessberg, G. A., Washburn, M.C., and Epker, B.N. An evaluation of mandibular rest positions in subjects with diverse dentofacial morphology. (Submitted for publication).
- Wessberg, B.A., Wesley, L.C., Dinham, R., and Wolford, L.M. Transcutaneous electrical stimulation as an adjunct in the management of myofacial pain dysfunction syndrome. *J.Prothat. Dent.*, 45:307-314, 1981.
- Williamson, E.H., and Bays, R.A. Unpublished data. Evans, GA: Foundation for Advanced Research and Training, 1985.
- Williamson, E.H., and Marshall, D. Myomonitor rest position in the presence and absence of stress. *Research Rep.* 1:14-16, 1986.
- Wood, C.R., Jr. Centrally related cephalometrics. *Am. J. Orthod.* 71:156, 1977.
- Wyon-Maillard, M-C., and Besson, J.M. Effects of orbital cortex stimulation on dorsal horn interneurons in the cat spinal cord. *Brain Res.* 46:71-83, 1972.
- Yaksh, T.L., and Rudy, T.A. Analgesia mediated by a direct spinal action of (narc. .?) *Science*, 192:1356-1358, 1976.
- Yavelow, I., Forster, I., and Wininger, M. Mandibular relearning. *Oral Surg.* 36:632, 1973.
- Yemm, R. Temporomandibular dysfunction and masseter muscles response to experimental stress. *Brit. Dent. J.*, 127:508-510, 1969.
- Yemm, R. Neurophysiologic studies of temporomandibular joint dysfunction. *Oral Sci. Rev.*, 7:31-53, 1976.
- Zak, E. Uber den Gefasskrampf bei intermittierendem Hinken und uber gewisse kapillomotorische Erscheinungen. *Wien. Arch. Inn. Med.* 2:405, 1921.
- Zieglgansberger, W., and Bayerl, H. The mechanisms of inhibition of neuronal activity by opiates in the spinal cord of cat. *Brain Res.*, 115:111-128, 1976.
- Zimmermann, M. Peripheral and central nervous mechanisms of nociception, pain, and pain therapy: facts and hypotheses. In: J.J. Bonica e al, Eds., *Advances in pain research and therapy*, vol. 3, pp. 3-32, New York, Raven Press; 1979.

LITERATURE REVIEW OF SCIENTIFIC STUDIES
SUPPORTING THE EFFICACY OF MANDIBULAR TRACKING
IN THE DIAGNOSIS AND TREATMENT OF TMD

INTRODUCTION

Progress in the field of mandibular tracking was limited by the capability of available instrumentation. As early as 1931 Hildebrand used cinematography of a moving reflective point to track mandibular movement (1). Cinefluorography was used by Klatsky in 1941 (2) and was followed by Kurth's use of stroboscopic photography in 1942 (3). Mechanical tracking has also been used by several investigators throughout the history of mandibular tracking in dentistry (4). The interference of mechanical tracking devices with normal mandibular function was a common problem. The first use of electronic recording techniques to record occurrence and duration of occlusal contacts during mastication was reported in 1953 (5). Brewer and Hudson later used miniaturized make or break switches to study tooth contact (6). Adams and Cannon developed instrumentation to trace actual movement patterns of the mandible during functional and parafunctional movements (7, 8).

In 1975 Jankelson defined the requirements and criteria for a mandibular tracking system that would provide reliable quantitative and reproducible data. The criteria are:

1. The relationship of the mandible to the maxilla must be determined in three dimensions.
2. Data output must be continuous to permit analysis of the dynamic components of mandibular function.
3. The system cannot encroach on the occlusal plane so as to interfere or alter proprioception.
4. To avoid unnatural proprioceptive input and minimize mechanical limitations on mandibular movement, no supporting structures or wires should protrude from the mouth.
5. The practical use of the system requires that setup time be minimal and that the system be self contained.
6. Measurement in the vicinity of the occlusal plane should be accurate to within 0.1mm.
7. The system should be widely available and operable by dental personnel (9).

Belser and Hannam demonstrated that an early model Myo-tronics Kinesiograph was capable of recording incisal point movement to within 0.3mm anywhere within the envelope of chewing (10). The same authors have used this instrumentation in other scientific studies, demonstrating their confidence in the capability and accuracy of this modality (11).

Today's Mandibular Kinesiograph is a computerized electronic measuring device that can track mandibular movement with 0.1mm plus or minus accuracy in three simultaneous planes as well as precisely measuring opening and closing velocity.

The value of this measurement capability to the clinical dentist responsible for establishing a predictable and accurate occlusal position diagnostically and therapeutically is self evident. The ability to record, measure and capture a desired occlusal position transcends occlusal philosophy.

The value of correlative data utilizing the MKG was emphasized in an AADR 1983 report by Bigelow, Slagle, and Chase, Department of Oral and Maxillofacial Surgery, University of Tennessee, entitled "Evaluation of Internal Derangement of TMJ with Mandibular Kinesiograph/ Arthrography" (25). The report stated:

"Arthrography has established the increasing frequency of internal derangement of the TMJ. Jankelson et al have developed the Mandibular Kinesiograph (MKG) to characterize abnormalities of the TMJ. This study demonstrates a positive correlation between patients with stages of internal derangements and diagnostic MKG tracings. 20 patients were examined in this study. Historical, physical and radiographic criteria were used to diagnose patients with internal derangement of the TMJ. Arthrography was then performed to evaluate the extent of abnormalities. Patients were grouped according to the presence of clicks on opening, closing or both. Also on arthrography findings: normal, anterior dislocation with reduction, or anterior dislocation without reduction. Velocity tracing of the MKG were compared concerning characteristic and morphologic patterns. The velocity tracings were classified according to the irregularities in the opening and closing velocities. Correlations occur between velocity tracings and the arthrogram presentation of internal derangement which resulted in reduction or nonreduction during jaw excursions. Patients with arthrographic diagnosis of internal derangement without reduction demonstrated MKG tracings of impaired vertical opening deviation toward the affected side and characteristic irregularities in the velocity tracing. Patients with reduction showed only deviation to the affected side. MKG evaluation appears to be a reliable means to diagnose internal derangement of the TMJ."

Following are controlled studies that further support the rationale for mandibular jaw tracking. The Mandibular Kinesiograph is a measurement modality. Measurement is the common index for all scientific disciplines. The evolution of every scientific discipline has depended upon development of improving measurement modalities. The literature is clear that dentistry is no exception.

INTRODUCTION TO MANDIBULAR TRACKING
SUPPLEMENTAL REFERENCES

1. Hildebrand, G.Y. Studies in masticatory movement of the human lower jaw. Scand. Arch. of Physio. Vol. 3, 1931.
2. Klatsky, M.A. A cineflourographic study of the human masticatory apparatus in function. Am. J. of Ortho. and Oral Surg. 26:664, 1941.
3. Kurth, L.E. Mandibular movements in mastication. JADA. 29:1769, 1942.
4. Boswell, J.V. Practical occlusion in relation to complete dentures. J. of Prosth. Dent. 1:307, 1951.
5. Jankelson, B., Hoffman, G.M. and Hendron, J.A. Physiology of the stomatognathic system. JADA. 46:375, 1953.
6. Brewer, A.A. Hudson, D.C. Application of miniaturized electronic devices to the study of tooth contact in complete dentures. J. Prosth. Dent. 11:62, 1961.
7. Adams, S.H. and Zanders, H.A. Functional tooth contacts in latent and in centric occlusion. JADA. 69:465, 1964.
8. Cannon, D.C., Reswick, J.B. and Messerman, T. Instrumentation for the investigation of mandibular movements. Report No. EPC464-8, Cleveland Engineering Design Center, Case Western Reserve Univ., 1964.
9. Jankelson, B., Swain, C.W., Crane, P.F. and Radke, J.C. Kinesiometric Instrumentation: A New Technology. JADA. 90:834-840, 1975.
10. Belser, U.C. and Hannam, A.G. Influence of altered working-side occlusal guidance on masticatory muscles and related jaw movement. J.Prosth. Dent. Vol. 53, No. 3, pp 406-413, March 1985.
11. Belser, U.C. and Hannam, A.G. The contribution of the deep fibers of the masseter muscle to selected tooth-clenching and chewing tasks. J.of Prosth. Dent. Vol. 56, No. 5, pp 629-635, Nov. 1986.
12. Feine, J.S., Hutchins, M.O. and Lund, J.P. "An evaluation of the criteria used to diagnose mandibular dysfunction with the mandibular kinesiograph." JADA. Vol. 60, No. 3, Sept. 1988.
13. Gibbs, C.H., et al. Functional movements of the mandible. J. Prosth. Dent. 26:604-619, Dec. 1971.
14. Clark, G.T. and Lynn, P. Horizontal plane jaw movements in controls and clinic patients with temporomandibular dysfunction. 55:730-735, 1986.
15. Monteiro, et al. Relationship between mandibular movement accuracy and masticatory dysfunction symptoms. J. of Cranio. Disorders: Facial and Oral Pain. Vol. 1, No. 4, pp 237-242, 1987.
16. Rosenbaum, M. The feasibility of a screening procedure regarding temporomandibular joint dysfunction. J. Oral Surg. 39:382-389, March 1975.
17. Rieder, C.E. Maximum mandibular opening in patients with and without a history of TMJ dysfunction. J. Prosth. Dent. Vol. 39, No. 4, pp 441-446, April 1978.
18. Balthazar, Y., et al. Limited mandibular mobility and potential jaw dysfunction. J. Oral Rehab. Vol. 14, pp 569-574, 1987.
19. Jemt, T. and Hedegard, B. Reproducibility of chewing rhythm and of mandibular displacements during chewing. J. Oral Rehab. Vol. 9, pp 531- 537, 1982.

20. Shields, et al. Using pantographic tracings to detect TMJ and muscle dysfunctions. *J. Prosth. Dent.* 39:80-87, 1978.
21. Van Willigen, J. The sagittal condylar movements of the clicking temporomandibular joint. *J. Oral Rehab.* 6:167-175, 1979.
22. Lederman, K. and Clayton, J. Patients with restored occlusions. Part I: TMJ dysfunction determined by a pantographic reproducibility index. *J. Prosth. Dent.* 47:198, 1982a.
23. Lederman, K. and Clayton, J. Restored occlusions. Part II: The relationship of clinical and subjective symptoms to varying degrees of TMJ dysfunction. *J. Prosth. Dent.* 47:304, 1982b.
24. Monteiro, A.A., et al. Relationship between mandibular movement accuracy and masticatory dysfunction symptoms. *J. Craniomand. Disord.: Facial and Oral Pain.* 1:237-242, 1987.
25. Bigelow, W.C., Slagle, W.F. and Chase, D.C. Evaluation of internal derangement of TMJ with mandibular kinesiograph/arthrography. *AADR Abstracts.* No. 675, 1983.

ARTICLES REVIEWED IN THIS PUBLICATION

SECTION 1: STUDIES THAT DOCUMENT JAW TRACKING (CMS) ACCURACY

1. Wessberg, G.A., Epker, B.N., and Elliott, A.C. The reliability of a Mandibular Kinesiograph. Hawaii Dental Journal, Vol. 15, No. 3, September 1984. See abstract page 142.
2. Jankelson, B. and Swain, C.W., et al. Kinesiometric instrumentation: a new technology. Journal of the American Dental Association, Vol. 90, pp 834-840, April 1975. See abstract page 144.
3. McMillan, D.R. and McMillan, A.S. A comparison of habitual jaw movements and articulator function. Acta Odontol Scand. (1986) 44, 291- 299. Oslo. ISSN 0001-6357. See abstract page 145.
4. Hannam, A.G., DeCou, R.E., Scott, J.D. and Wood, W.W. The kinesiographic measurement of jaw displacement. J. of Prosthetic Dentistry. Vol. 44, 88-93, July 1980. See abstract page 146.

SECTION 2: STUDIES THAT DOCUMENT THE VARIATION IN MANDIBULAR FUNCTION IN NORMAL VERSUS ABNORMAL POPULATIONS

1. Maruyama, T., Miyauchi, S., Umekoji, E. and Simoosa, T. Analysis of the relationship of centric relation and centric occlusion by the Mandibular Kinesiograph. J. Osaka Univ. Dent. Sch. Vol. 20, 173-178, 1980. See abstract page 148.
2. McCall, W.D., Jr., Bailey, J.O., Jr., and Ash, M.M., Jr. A quantitative measure of mandibular joint dysfunction: Phase plane modelling of jaw movement in man Archs Oral Biol. Vol. 21, pp 685 - 689. Pergamon Press 1976. Printed in Great Britain. See abstract page 150.
3. Griffin, C.J. Diagnosis and treatment of mandibular displacements by mandibular kinematography. The dental nociceptive reflex. Australian Dental Journal. pp 384-392, Oct. 1963. See abstract page 152.
4. Mongini, F.. A graphic and statistical analysis of the chewing movements in function and dysfunction. The J. of Cranio. Pract. Vol. 2, No. 2, March-May 1984. See abstract page 154.
5. Ow, R.K.K., Carlsson, G.E., and Jemt, T. Craniomandibular disorders and masticatory mandibular movements. J. of Craniomandib. Disord.: Facial & Oral Pain. 1988; Vol 2, No. 2, 96-100. See abstract page 156.

SECTION 3: STUDIES THAT DOCUMENT THE CLINICAL EFFICACY AND VALIDITY OF MANDIBULAR TRACKING

1. Jankelson, B. Three dimensional orthodontic diagnosis and treatment: A neuromuscular approach. J. of Clinical Orthodontics. Vol. XVIII, No. 9, Sept. 1984. See abstract page 158.
2. Callender, J.M. Orthodontic application of the Mandibular Kinesiograph: Part II. J. of Clinical Orthodontics. Vol XVIII, No. 11, pp 791-805, Nov. 1984. See abstract page 159.
3. Callender, J.M. Orthodontic application of the Mandibular Kinesiograph: Part I. J. of Clinical Orthodontics. Vol XVIII, No. 10, pp 710-718, Oct. 1984. See abstract page 204.
4. George, J.P., and Boone, M.E. A clinical study of rest position using the Kinesiograph and Myomonitor. The Journal of Prosthetic Dentistry. Vol. 41, No. 4, pp 456-462, April 1979. See abstract page 162.
5. Konchak, P.A., Thomas, N.R., Lanigan, D.T., and Devon, R. Vertical dimension freeway space, a kinesiographic study. The Angle Orthodontist. pp 145-154, April 1987. See abstract page 165.
6. Wessberg, G.A., Epker, B.N., and Elliott, A.C. Comparison of mandibular rest positions induced by phonetics, transcutaneous electrical stimulation, and masticatory electromyography. The Journal of Prosthetic Dentistry. Vol. 49, No. 1, pp 100-105, January 1983. See abstract page 167.
7. Crandall, J.A. Evaluation of mandibular movement and range of motion in the diagnosis of craniomandibular disorders. J. of Craniomandib. Pract. Vol. 4, No. 3, pp 234-245, July 1986. See abstract page 168.

SECTION 4: STUDIES UTILIZING MANDIBULAR TRACKING FOR RESEARCH PROTOCOLS

1. Belser, U.C., and Hannam, A.G. The influence of altered working-side occlusal guidance on masticatory muscles and related jaw movement. *The Journal of Prosthetic Dentistry*. Vol. 53, No. 3, pp 406-413, March 1985. See abstract page 170.
2. Konchak, P., Thomas, N., Lanigan, D., and Devon, R. Freeway space measurement using mandibular Kinesiograph and EMG before and after TENS. *The Angle Orthodontist*. pp 343-350. See Abstract on page 171.
3. Hannam, A.G., et al. The relationship between dental occlusion, muscle activity and associated jaw movements in man. *Archives Oral Biol*. 22:25, 1977. See abstract page 174.
4. Belser, U.C., and Hannam, A.G. The contribution of the deep fibers of the masseter muscle to selected tooth-clenching and chewing tasks. *J of Prosthet Dent*. Vol. 56, No. 5, pp 629-635, Nov. 1986. See abstract page 177.
5. Nielsen, I.L., Ogro, J., McNeill, C., Danzig, W.N., Goldman, S.M., and Miller, A.J. Alteration in proprioceptive reflex control in subjects with craniomandibular disorders. *J. of Craniomandibular Disorders: Facial and Oral Pain*. Vol. 1, No. 3, pp 170-178, 1987. See abstract page 178.
6. Neill, D.J. and Howell, P.G.T. Computerized kinesiography in the study of mastication in dentate subjects. *J. of Prosthet. Dent*. Vol. 55, No. 5, pp 629-638, May 1986. See abstract page 181.
7. Hannam, A.G., Scott, J.D., and De Cou, R.E., A computer-based system for the simultaneous measurement of muscle activity and jaw movement during mastication in man. *Archs Oral Biol*. Vol. 22, pp 17-23, Pergamon Press, 1977. See abstract page 183.

STUDIES THAT DOCUMENT JAW TRACKING (CMS) ACCURACY

Wessberg, Epker and Elliot evaluate the Mandibular Kinesiograph and conclude that it is far superior to conventional methods of direct measurement despite the inherent non-linearity at wide openings for C.O. The accuracy, reproducibility and linearity make the instrument valuable for clinical purposes.

Wessberg, G.A., Epker, Bruce, N., and Elliott, A.C. The reliability of a Mandibular Kinesiograph. Hawaii Dental Journal. Vol 15, No. 3, September 1984.

ABSTRACT

Reliable and physiologically compatible measuring devices are essential to clinically relevant studies of the human stomatognathic system. This investigation was done to evaluate the accuracy, reproducibility, and linearity of one such instrument, a mandibular kinesiograph. This electronic device was found to be accurate to 4.4 percent of vertical mandibular displacement with clinically tolerable variations in reproducibility and linearity. Despite this variability, the kinesiograph appears far superior to conventional methods of direct measurement of a biologically dynamic entity such as the mandibular rest position.

SUMMARY

The clinical reliability of a mandibular kinesiograph was evaluated on the basis of accuracy, reproducibility, and linearity. Although the statistical analysis reveals this instrument to be inherently inaccurate and nonlinear, it is still a valuable apparatus for specific types of clinical investigation. Therefore, the tremendous physiologic advantage of indirect measurement of mandibular movement demonstrated by the kinesiograph is superior to other methods presently available.

ACCURACY

The overall accuracy of the mandibular kinesiograph was determined by analyzing the difference between the actual vertical displacement of the mandibular incisor tooth induced by the occlusal jig and the indirect measurement displayed on the kinesiograph for the five subjects at the five trials at each of the four vertical positions. The mean error for these 100 recordings was +4.4 percent. In addition, tolerance intervals were calculated to predict the accuracy of a solitary clinical trial (Table 1). These calculations revealed that a 95 percent level of confidence may be assumed for 95 percent of the readings within an interval of -15.8 percent to +24.6 percent (Dixon, W.3., and Massey, F.J., 1969).

Barlett's test for homogeneity of variance showed that the variance decreased significantly ($p < 0.001$) from the 3-millimeter position to the 15- millimeter position. Thus, the graph in Fig. 3 suggests that accuracy improves as the vertical displacement of the mandible increases.

REPRODUCIBILITY:

The reproducibility of the kinesiograph within a single position was determined by analyzing the accuracy for each subject at the four positions of vertical displacement. The percentage of error calculated for the 25 trials at each position and the tolerance interval for a 95 percent level of confidence for 95 percent of the trials are listed in Table 1. These results are also illustrated graphically for each of the five subjects in Fig. 4.

LINEARITY:

The linearity of the kinesiographic recordings from 3 to 15 millimeters was examined by plotting the mean values obtained for each subject at each of the four positions of vertical displacement. These values are illustrated graphically in Fig. 4. The gray area adjacent to the line connecting these mean values represents two standard errors of the mean. There was no statistical support to conclude that the relationship was linear.

DISCUSSION

The results of this study reveal the clinical reliability of a mandibular kinesiograph. The accuracy, reproducibility, and linearity of this instrument were evaluated by conducting five separate trials at four fixed distances of vertical mandibular displacement in five individuals.

The accuracy of the kinesiograph was determined to be 4.4 (T.I. = -15.8, 24.6) percent at the 95 percent level of confidence for 95 percent of the measurements within the parameters studied. Jankelson reported an accuracy of -3 percent at 20 millimeters of vertical displacement (Jankelson, B.; Swain, C.W.; Crane, P.F.; and Radke, J.C., 1975). Hannam et al. employed a micromanipulator to bench-calibrate a kinesiograph and reported an accuracy of +0.25 millimeters anywhere within a spatial column 20x20x40 millimeters (Hannam, A.G.; Scott, J.D.; and De Cou, R.E., 1977). These authors did not report a confidence level with their values for comparison with our values.

The gain setting is probably the cause of the apparent increase in accuracy with an increase in the vertical mandibular displacement. A gain of 1 was employed for measurements of 3 and 5 millimeters, a gain of 2 for 10 millimeters, and a gain of 5 for 15 millimeters. The need to increase the gain to permit measurement of these greater distances minimizes the variability.

The reproducibility of the kinesiograph was determined to be 6.6 (T.I. = 24.9, 38.1) percent at 3 millimeters and 2.7 (T.I. = 10.8, 16.2) percent at 15 millimeters at the 95 percent level of confidence for 95 percent of the measurements. Hannam et al. reported a reproducibility of 2.1 percent at 20 millimeters of vertical displacement after five trials on one subject. Again, no level of confidence was reported for this value.

Jankelson and Swain introduce a method of monitoring mandibular movement in three planes by use of magnetometers. The magnetometers sense change in the magnetic field which results from movement of a permanent magnet attached to the lower incisors. In this manner, jaw movement is tracked vertically, anteroposteriorly and laterally in addition to measuring mandibular acceleration. This study published in the Journal of the American Dental Association was the first to introduce the capabilities of the Mandibular Kinesiograph for clinical diagnosis and research.

Jankelson, B., and Swain, C.W., et al. Kinesiometric instrumentation: A new technology. Journal of the American Dental Association. Vol 90, pp 834-840, April 1975.

SYSTEM DESCRIPTION AND THEORY OF OPERATION

The Mandibular Kinesiograph pictured in Figure 1 is the result of system evolution over several years. The system senses the spatial location of a permanent magnet that is mounted on the mandibular incisors with a dental plastic as shown in Figure 2. (setup time for each patient is about three minutes.) The system does not alter proprioceptive input either by interfering with the occlusal plane or by limiting the normal range of mandibular function.

The Mandibular Kinesiograph provides an accuracy of 0.1 mm for resolution of mandibular positions in the vicinity of occlusion. At a vertical opening of 20 mm, the geometric error is approximately -3% in the vertical channel, +5.7% in the anteroposterior channel, and, of course, 0% in the lateral channel because of its differential nature. There is, however, a corresponding gain-loss error in the lateral channel of about -6% when the mandible is deviated 10 mm left or right at a 20 mm vertical opening; (that is, if the jaw is positioned 10 mm to the left of center at a 20 mm vertical opening, the Kinesiograph will read out a 9.4 mm change in lateral position to the left).

For increased accuracy with large motions away from occlusion, a computer program has been written and is in use, according to an oral report by A. Hannam, department of oral biology, University of British Columbia, that corrects the system errors to a maximum of 0.5 mm anywhere within a 40 mm vertical opening, for + or - 10 mm of anteroposterior motion, and 10 mm left or right; this more than covers the range of function.

SUMMARY

The development of the Mandibular Kinesiograph presents dental professionals with a convenient, physiologically commutable method of monitoring mandibular movements. The analysis of mandibular kinesiology during mastication, deglutition, and speech has already shown itself to be a fruitful area of inquiry. Innovative use of this system in the research and diagnostic environment will undoubtedly provide clinicians with the data base necessary to evaluate individual patient records.

McMillan and McMillan, in a controlled study utilizing the Mandibular Kinesiograph to record three dimensional mandibular movement, conclude "Identification of errors in the recording of direction and magnitude of movements of an incisal point by the Kinesiograph does not detract from its utility or importance as an instrument by means of which movements of the mandible can be visualized quantitatively and qualitatively in three orthognathic planes.

McMillan, D.R., and McMillan, A.S. A comparison of habitual jaw movements and articulator function. *Acts Odontol Scand.* 1986; 44:291-299. Oslo. ISSN 0001-6357.

Inherent in adjustable articulators are errors related either to recordings from the patient or to adjustments to the instrument, or both. Furthermore, the validity of the geometric concepts on which the design of these instruments is based, stressing the dominant role of the temporomandibular joints in mandibular movements, is open to question. Microchip technology now makes it possible to view jaw movements in three dimensions while impeding physiological activity minimally. Using a kinesiograph, young dentate Swedish and Chinese adults were examined on two occasions, and the magnitude and direction of some jaw movements were recorded. The results showed that voluntary opening and closing excursions of the mandible frequently followed disparate paths and that closure from the rest position to occlusion was three-dimensional, a lateral component of movement being usual. Retruded contact position was both uncomfortable and unstable. These findings suggest that current procedures for designing and refining occlusal schemes on articulators are invalid. Articulators; dental occlusion; prosthetics.

DISCUSSION

Identification of errors in the recording of the direction and magnitude of movements of an incisal point by the kinesiograph does not detract from its utility or importance as an instrument by means of which movements of the mandible can be visualized qualitatively and quantitatively in three orthogonal planes. This is particularly the case in relation to three-dimensional movements that occur in close proximity to the intercuspal position, where the instrument error is minimal.

CONCLUSIONS

No evidence emerged to suggest that the mandibular movements executed by the subjects in this study occurred about a single, fixed hinge axis. The occlusal terminus for movements was at the intercuspal position. Motion from RP to ICP involved a lateral component of movement in addition to those in vertical and horizontal directions. Voluntary retrusive movement from ICP to RCP also incorporated a lateral component, as did protrusive movements. Retruded contact position was both strained and unstable. Whereas articulators are useful in tooth setting and in designing of occlusal schemes for fixed prostheses, their use in diagnosis and the ultimate refinement of occlusion may introduce errors rather than facilitate their removal, since they cannot mimic the crucial threedimensional movements required.

Hannam, et al, presents a method to help linearize kinesiograph measurements. A thorough analysis of kinesiograph capabilities and limitations is presented in this study. The study concludes that day to day expression with acceptable error of measurement of linear incisor movement can be achieved with the kinesiograph.

Hannam, A.G., DeCou, R.E., Scott, J.D. and Wood, W.W. The kinesiographic measurement of jaw displacement. J. of Prosthetic Dentistry. Vol. 44:88-93, July 1980.

Functional movements of the jaw have been recorded by a variety of methods including direct observation, cinematography, electromagnetically inductive and photoconductive transducers, and, most recently, radionuclide tracking. (Bates, J.F., 1975, Hannam, A.G., 1979)

During normal movements, the translations and rotations which accompany jaw motion are so complex that only those systems capable of expressing information with 6 degrees of freedom are properly able to measure displacement patterns at a given point. (Gillings 1973, Goodson 1975, Lemmer 1976) Although such devices exist, (Gibbs 1971, Suit 1976) most studies have been carried out with techniques involving two or three degrees of freedom and they have been confined to the description of incisor point movement only. (Bates 1975, Hannam 1979) Reasons for the acceptance of limited expressions of motion probably include the relative noninvasiveness of incisor point movement, the physical ease of the technique, its applicability to large numbers of subjects, the restriction of data to manageable proportions, and not least, the general lack of alternative instrumentation with desirable properties.

Several investigators have used the Kinesiography to monitor three- dimensional linear movement of an incisor point on the mandible. (Jankelson 1975, Morimoto 1977, Hannam, Scott, et al., 1977, Hannam, De Cou, et al., 1977) Apart from major theoretical limitations as outlined, the instrument offers properties which should be taken into account whenever quantitative measurement is contemplated. This article describes how they can be controlled in an experimental environment.

METHODS

The Kinesiograph basically consists of a set of magnetometers which sense the displacement, in three planes, of a small magnet cemented to the lower anterior teeth. These sensors are carried on a light framework supported by a spectacle-like device which is worn by the patient in a conventional fashion and stabilized with an elastic strip behind the head. The framework is arranged about the magnet in a prescribed way and usually zeroed to the intercuspal position of the patient before any recordings are carried out. The fundamental signals derived from the device are three voltages representing vertical, lateral, and anteroposterior jaw movement, respectively. The voltages are referenced to the planes of orientation of the magnetometers. This system is described in more detail elsewhere. (Jankelson 1975)

During bench tests, we have found the instrument to be a stable indicator of the position of the magnet provided the latter is not rotated. It responds acceptably to frequencies of displacement up to 150 Hz.

Aside from these limitations, two other aspects of the instrument's performance are notable. These are its inherent nonlinearity over certain prescribed ranges of linear displacement and the question of its orientation relative to craniofacial landmarks. Our observations concerning the management of both aspects are based upon experience with the earlier, K2 version of the Kinesiograph. The principles involved, however, can be applied equally to later versions of the instrument.

NONLINEARITY

The position of the magnet relative to the sensors on the framework of the kinesiograph determines the nature of the nonlinearity. If the magnet-to-frame relationship during set-up is as the manufacturers suggest, distortions are least near the intercuspal position (the zero point) and greatest at the more extreme positions, for example, near maximum opening or maximum lateral excursions.

Because any correcting operation has its greatest source of error where the distortion is most marked, it is prudent to first determine the range of movement anticipated under operational conditions and then to choose a set-up zeroed position of magnet-to-frame which is best able to distribute the nonlinearity as evenly as possible over the user's intended range. If, as in many cases, the entire range of the masticatory cycle is to be included, we have found it better to set the magnet 1 cm higher than suggested by the manufacturers. This not only serves to improve the distribution of the distortion but has the practical benefit of permitting added clearance between the chin and the lower sensor.

Positioning the framework is approximate at best. The method nevertheless ensures that consequent errors are at least minimized. In a previous experiment, (Hannam, Scott, et al., 1977) we have used it repeatedly (15 times over 3 days) to remeasure a standardized jaw position in the same subject. The mean coordinates of this fixed point were estimated to be 19.3 mm SD + 0.4 mm vertical, 3.2 mm SD + 0.8 mm lateral, and 3.5 mm SD + 1.3 mm anteroposterior (n = 15), the variances expressing errors due to frame placement alone.

We believe that it may be possible to reduce errors in day-to-day measurement still further by referencing the framework to the maxillary dental arch. Before each recording session, a bite-fork registration of the arch can be made with conventional face-bow apparatus. At the end of the session, but before the Kinesiograph framework is removed, the bite-fork record is reinserted and held rigidly by the subject. The hinge-axis and orbital indicators are then reversed and aligned so as to signify coplanar points on the two lateral and single vertical sensors of the Kinesiograph. On its removal, this modified face-bow record indirectly provides a measure of the angular relationship between the actual reference planes of the Kinesiograph during the recording session and the conventional reference planes of semiadjustable or fully adjustable articulators.

The maxillary dental arch provides the common reference for relating one data set to the other: therefore, any simple measuring device can be used to estimate angular relationships between the two sets of planes.

DISCUSSION

More efficient, and perhaps more accurate, methods for linearizing and referencing the system may be possible than those described here. Whether these are worth pursuing depends upon the user's needs. In terms of bench performance with a linear calibrator, the instrument can resolve small changes in displacement, and it is theoretically possible, following suitable filtering procedures, to devise very accurate linearizing procedures under these conditions. These efforts, however, must be balanced against the fixed limitations inherent in the overall system, which produce errors that are difficult or impossible to control under functional conditions. Rotations at or around the incisal point cannot be measured, while the process of physical orientation and fixation of the apparatus is at best an imprecise exercise.

However, once the decision is made to accept the instrument's restriction to expressing linear but not rotational motion of a single incisor point, the remaining limitations of the Kinesiograph can clearly be minimized to an extent that permits acceptable errors of measurement for many tasks. Such procedures may be entirely unnecessary if the system is only used to display jaw movements in a qualitative way. On the other hand, if comparative measurements are to be performed on a day-to-day basis, especially outside the intercuspal area, then additional techniques of this kind are obviously essential.

Although the suggested principle of zeroing the system to the intercuspal position seems to be satisfactory for most purposes, the alterations to this area which occur as a consequence of occlusal or orthognathic reconstruction frequently require the zeroed position to be related to more fixed, conventional, mandibulomaxillary references such as centric relation. This is especially true when there is an ambiguity in the intercuspal position, for example, in patients with excessive occlusal wear, or with "freeway in centric relation." In this regard, it should be added that external manipulation of the mandible when the framework is in place can be difficult.

Several points have been mentioned which are not peculiar to the Kinesiograph alone. Any system used for measuring jaw movement should be recalibrated at regular intervals and under conditions resembling the actual recording environment as closely as possible. Identifiable planes of reference must be used and some kind of estimation made of the errors associated with placing the transducers on the subject. Finally, any system, whether it records the displacement of one or several points on the mandible in more than one dimension, creates a formidable problem in data management and its expression. Under these circumstances, digital conversion becomes an almost essential part of the process whenever quantitative measurement is contemplated.

CONCLUSIONS

Whenever the Kinesiograph is used to measure functional jaw movement, three factors should be taken into account. The instrument is theoretically limited by its expression of data with only 3 degrees of freedom of measurement, it has nonlinear response characteristics over the entire range of functional jaw movement, and it requires referencing to fixed craniofacial landmarks. Although the first limitation is inherent in its design and cannot be altered, the remaining two can be controlled sufficiently to permit the day-to-day expression with an acceptable error of measurement of linear incisor movement.

STUDIES THAT DOCUMENT VARIATION IN MANDIBULAR FUNCTION IN NORMAL VERSUS ABNORMAL POPULATIONS

Maruyama, et al, in a controlled study utilizing the Mandibular Kinesiograph and 70 subjects with normal occlusion quantitated the displacement between centric relation and centric occlusion. None of the 70 subjects showed coincidence of centric relation and centric occlusion. The expression of three dimensional deviation with the Mandibular Kinesiograph was a significant improvement over previous methods using one dimensional measurements to evaluate normal and physiologic relationships between maxilla and mandible.

Maruyama, T., Miyauchi, S., Umekoji, E., and Simoosa, T. Analysis of the relationship of centric relation and centric occlusion by the Mandibular Kinesiograph. J. Osaka Univ. Dent. Sch. Vol 20, 173-178, 1980.

ABSTRACT

Three-dimensional relationship between centric relation and centric occlusion in human normal occlusion was analysed by using the Mandibular Kinesiograph, in order to know the normal and physiological relationship between maxilla and mandible in occlusal equilibration, occlusal reconstruction or oral rehabilitation.

The mean distance and standard deviation between centric relation and centric occlusion of anteroposterior, supero-inferior, right lateral, left lateral and linear directions at the mandibular incisor were 1.30. mm (S.D. 0.91 mm), 0.75 mm (S.D. 0.54 mm), 0.29 mm (S.D. 0.30 mm), 0.38 mm (S.D. 0.29 mm) and 1.53 mm (S.D. 0.81 mm), respectively. All the subjects showed anteroposterior deviation, most of the subjects showed superoinferior deviation.

MATERIALS AND METHODS

The subjects in the study consisted of 70 individuals (26 women and 44 men) between the ages of 23 and 35 years. All subjects had normal occlusion and no poor restorations and no complaints relative to the temporomandibular joints or masticatory muscles.

The magnet was positioned on the labial surfaces of the mandibular incisors and gingiva using the Myo-print resin (Myotronics Inc., Seattle Washington) horizontally in the vestibule with the "N" towards the patient's left. The magnet was centered on the mandibular incisors with its long axis parallel to the plane of occlusion.

The sensor array was placed and adjusted as follows: a) Rotational adjustment; the central struct of the array was positioned perpendicular to the floor. b) Anteroposterior adjustment; the array was moved anteriorly or posteriorly until the magnet was centered between the lateral sensors. c) Vertical and lateral adjustment: the array was moved up or down until the magnet was centered vertically on the midline.

The recording procedures of centric relation and centric occlusion were as follows: a) The subject was asked to open and close for several times with his jaw pull back as far as possible until a light contact of the teeth was obtained. If the subject could not pull back his jaw by himself, the operator applied his hand to support the subject's jaw and help to open and close in centric relation. This recording was terminal hinge closure and centric relation contacts. b) Then, the subject was asked to open and close into maximum intercuspal position for several times. This recording was habitual closure and centric occlusion contacts. c) The sagittal and frontal recordings of centric relation and centric occlusion on the oscilloscope were photographed by the Polaroid camera.

DISCUSSION

Various investigations concerning the mandibular displacement between centric relation and centric occlusion have been performed. Posselt (1952) reported that 88% of 50 dental students could displace their mandibles posterior to the occlusal position. He showed that the mandible at the lower incisors moved posteriorly 1.25 mm+1.0 mm, and caudally 0.9 mm+0.75 mm from the intercuspal position using cephalometric roentgenogram. Kydd and Sander (1961) reported 100% of 14 subjects could show the posterior movement with the mean of 0.87 mm+1.00 mm, using serial roentgenograms. Ingervall (1964) reported all of 29% subjects showed the mean difference of 0.85 mm+0.35 mm between centric relation and centric occlusion. Remien and Ash (1974) reported the difference with the mean of 0.75 mm between centric relation and centric occlusion recorded by contact of the pin to the table of the Hight Tracer attached to the patient's mouth with clutches, and reported the difference ranging from 1.5 mm to 3.5 mm, with the mean of 2.2mm.

In our study, the means and S.D.s of the distance of anteroposterior, superoinferior, right, left and linear direction between centric occlusion and centric relation were 1.30 mm (0.91 mm), 0.75 mm (0.54 mm), 0.29 mm (0.30 mm), 0.38 mm (0.29 mm) and 1.53 mm (0.81), respectively. The means of the distance of anteroposterior and linear direction were slightly larger than the data reported by some of other investigators. It was because of the following reason. As the measuring point in this study was on the labial surfaces of the mandibular incisors and gingiva, the distance from the condyle was longer than other methods. If the deviation between centric relation and centric occlusion was one-dimensional, the position of the measuring point did not effect on the value of the measurements. But, as the deviation was three-dimensional, the value of the measurements became larger, when the measuring point was away from the condyle.

From the results that none of 70 subjects showed the coincidence of centric relation and centric occlusion in anteroposterior direction, the existence of the small distance or freedom between centric relation and centric occlusion in anteroposterior direction might be physiological phenomenon for an optimum occlusion.

McCall, et al, recorded jaw movement using a Hall-effect generator and a magnet attached to the lower incisors. Using computer programs, the authors established a mathematical model to reference the experimental data. Large model/experimental discrepancy was indicative of dysfunction with predictive success via accepted occlusal therapy. The study concluded that phase plane modeling provides quantitative measurement of joint dysfunction useful for monitoring treatment progress and identifying those cases which will respond favorably to occlusal therapy.

McCall, W.D., Jr., Bailey, J.O., Jr., and Ash, M.M., Jr. A quantitative measure of mandibular joint dysfunction: Phase plane modelling of jaw movement in man. Archs Oral Biol Vol 21, pp 685 - 689. Pergamon Press 1976. Printed in Great Britain.

METHODS

TRANSDUCER

Jaw motion was registered by cementing a small permanent magnet on a mandibular incisor and recording its magnetic field at a maxillary incisor with a magnetic field-sensing device (Kydd, Harrold and Smith, 1967; Bando et al., 1972; Woltjen et al., 1973; Jankelson et al., 1975). The device was a Hall-effect generator (Model HI-5, American Aerospace Controls, Farmington, N.Y.). It was sensitive to the static magnetic field and was not influenced by saliva, tongue, food bolus etc. in the intervening space. The output of the α -43H generator was amplified and stored on analogue magnetic tape as part of a larger series of experiments. Typical raw data, including concurrent electromyographic (EMG) traces which will not be discussed here, are given in Fig. 1.

DATA PROCESSING

The term "phase plane" arose in the study of non-linear differential equations and their engineering applications (Hsu and Meyer, 1968). There, the term denotes a plot of any dependent variable vs. its time derivative. Here, phase plane refers specifically to the plot of jaw position vs. jaw velocity.

MATERIAL

The data from 9 clinically normal subjects and from 13 patients clinically diagnosed as having masticatory dysfunction were analyzed. Of the 13, 9 were responsive to treatment. The other 4 patients were refractory to treatment.

RESULTS

A typical phase-plane trajectory (a plot of jaw closing velocity vs. jaw position) from a normal subject started at an open jaw position and zero velocity (Fig. 3). As the distance decreased toward closing, the magnitude of the velocity increased smoothly to a maximum, and then rapidly decreased to zero at tooth contact. The rms error in normal subjects ranged from 10.5 to 18.7 per cent.

A typical phase plane trajectory from a dysfunctional patient prior to treatment by an occlusal splint showed large alterations of the velocity during closing (Fig. 4A).

After successful splint treatment, the amplitude of the velocity excursions was markedly attenuated compared to the pre-treatment trajectories (Fig. 4B). The error ranged from 7 to 17.5 per cent for successfully treated patients. The criterion for successful treatment was cessation of symptoms for a period of at least one month; these patients were then considered to be clinically normal.

Histogram of the rms error between the parabolic model and the experimental data (Fig. 5) showed that normal subjects and successfully treated patients fell, without exception, in the range of less than 20 per cent. The dysfunctional patients who were subsequently treated successfully by an occlusal splint showed, with one exception, a phase plane error at the pretreatment recording session which exceeded 20 per cent.

There were four exceptions to the general finding that patients with symptoms exceeded 20 per cent error and asymptomatic patients showed less than 20 per cent error. These patients were clinically diagnosed as having masticatory dysfunction but showed rms errors that would place them in the normal range of the histogram. The dysfunctional patients with large rms errors showed cessation of symptoms within a few weeks or even days with splint therapy; however, the four with small initial rms errors were refractory to the splint treatment for several months. Thus, by the method we report, it is possible to separate the dysfunctional patients into two groups; those who can be successfully treated and those who cannot be successfully treated by occlusal splint therapy alone.

DISCUSSION

CLINICAL

It should be stressed that the idea of an “ideal” patient fitting an “ideal” parabola was not intended; the parabola was used only for convenience. There is no rational basis for attaching any clinical significance to the parabolic shape.

The mechanism which caused the velocity alterations in the dysfunctional patients is of great interest as it might provide some insight into the aetiology of the individual problem. The possible mechanisms include mechanical impediment in the joint or its capsular structures, alteration of muscular activity and peculiarity in the transducer system. Each may be excluded by the appropriate experiments: The contention that the velocity alterations arose wholly within the transducer system can be rejected because the device was monotonic in static calibration and had no dynamic properties to cause such a phenomenon. Moreover, normal subjects exhibited smooth velocity increases and dysfunctional patients who had been successfully treated exhibited markedly attenuated velocity alterations.

Alterations in muscle activity would be observed in the simultaneous electromyographic tracings if techniques were developed to correlate the EMG with the jaw motion traces. We have not done so yet.

Regarding impediment in the joint itself, the possibility exists that the mechanisms causing clicking and crepitation are responsible for the velocity alterations on a purely mechanical basis.

Given previous separation by clinical examination into symptomatic and asymptomatic groups, the jaw motion technique we report here may provide a further separation of the symptomatic patients into two groups: Those who can and those who cannot be successfully treated by an occlusal splint. The phase plane method may also provide a quantitative method for monitoring the treatment progress of those dysfunctional patients who are responsive to occlusal techniques. It provides objective evidence, to support the subjective report of the patient, that the treatment has been successful.

Griffin, at the University of Sidney, recorded three dimensional mandibular movement using a mechanical mandibular kinematograph. Griffin concluded that jaw tracking evidence showed beyond reasonable doubt that TMJ dysfunction and its sequellae are related to mandibular displacement and that masticatory muscle asynergy in dysfunction is identifiable in variations of mandibular movement. The value of tracking mandibular relationships in assessing the status of the masticatory mechanisms is emphasized by the author.

Griffin, C.J. “Diagnosis and treatment of mandibular displacements by mandibular kinematography. The dental nociceptive reflex.” Australian Dental Journal. pp 384-392, Oct. 1963.

Opening and closing the jaws to and from centric occlusion is ideally achieved by paired symmetrical muscles acting synergistically. This synergy of the masticatory muscles is depicted kinematographically as smooth strokes; on the other hand, asynergism is depicted kinematographically as abrupt horizontal or obliquely horizontal strokes. When asynergy is observed it must be considered pathological. Kinematographic evidence suggests that the muscles responsible for this asynergism are usually the lateral pterygoids and their antagonists the posterior horizontal fibres of the temporal muscles. The muscles most susceptible to trauma in strained temporocondylar relationships are the lateral pterygoids and pressure on their tendinous insertions into the meniscus and pterygoid fovea, by virtue of the Golgi tendon organs, would cause their inhibition and excitation of their antagonists. Inhibition of say the right pterygoid muscle would be seen kinematographically as a deviating left stroke during the initial opening movement of the mandible. This is because failure of its contracture prevents medial forward translation of the right condyle, hinge movement however being permissible. At a certain part of the opening movement the involved muscle is freed of pressure, it then contracts suddenly causing a right horizontal or right obliquely horizontal kinematographic stroke depicting an abrupt left deviating movement of the mandible. This is usually associated with strepitus menisci. (Griffin 1962) The mandible on closing is brought back into the displaced position by the elevators, predominantly excessive contraction of the posterior horizontal fibres of the right temporal muscle. It can be stated that asynergy is the result of untreated mandibular displacements and constitutes temporomandibular joint arthritis. When F.C.M. K.'s are taken a left traverse of the panel augments a right kinematographic stroke and a right traverse of the panel augments a left kinematographic stroke.

MANDIBULAR DISPLACEMENT

Mandibular displacements of any type must be considered as potentially pathological and as playing a factor in the aetiology of periodontal disease. Prior to orthodontic treatment they ought to be assessed and therapy planned in such a way that it does not counteract against the predominant muscle play. Similarly occlusal equilibration techniques ought to be planned in accordance with the existing maxillo-mandibular relationships. Mandibular displacements may be diagnosed kinematographically as follows:

1. A posterior displacement of the mandible is diagnosed by the fact that the terminal closing movement to the tooth position is posterosuperior.
2. An anterior displacement is diagnosed by the fact that the terminal closing movement to the tooth position is excessively anterior and that the kinematographic stroke depicting this movement is excessively obliquely horizontal. Usually the amplitudes of the kinematograms are excessive.
3. A lateral displacement is diagnosed by a left divergent or right divergent kinematographic stroke depicting the terminal closing movement to the tooth position.
4. A combination of these displacements is diagnosed by comparing F.M.K.'s with L.M.K.'s. They may be classified as follows: (i) A left postero-lateral displacement; (ii) a right postero-lateral displacement; (iii) a left antero-lateral displacement; (iv) a right antero-lateral displacement.
5. A compensated mandibular displacement is diagnosed by the synergy of the compensatory muscle movements. That is by smooth compensatory kinematographic strokes depicting the closing compensatory mandibular movement. In a compensated mandibular displacement the stroke depicting the opening movement of the mandible is usually nearly vertical, whereas the closing stroke diverges right or left as the mandible closes to the tooth position. This is because the D.N.R. corrects the displacement as far as the mandibular depressors are concerned.

6. An uncompensated mandibular displacement is diagnosed by the asynergy of the mandibular depressors, and is usually associated with strepitus menisci. This is because the D.N.R. is inhibited. Whereas synergistic mandibular displacements ought to be considered as potentially pathological, asynergistic mandibular displacements especially when the mandibular depressors are involved must be considered as definitely pathological. In this instance a diagnosis of temporomandibular joint arthritis is justifiable.
7. Kinematographic evidence suggests that the D.N.R. is only fully disclosed when there has been a considerable loss of vertical dimension, or when by reason of malocclusion there is a considerable contact pathway from contact to maximum contact. The vertical distance of the apex of this reflex above the clench line usually indicates the amount of space utilizable in oral rehabilitation. However, in temporomandibular joint dysfunction the reflex cannot usually be elicited, not even the reflex artefact. This is indicative of inhibition of the mandibular depressors.
8. Reflex incoordination may sometimes be assessed on the basis of patients' ability to keep the head still during exercises. Most patients have no difficulty but patients with T.M.J. disturbances usually find it impossible to keep their heads still during recordings.

DISCUSSION

One of the features of the symptomatology of mandibular displacements is the fact that they symptoms either appear to be predominantly local or predominantly reflex in nature. They all, however, have one feature in common, asynergy of the masticatory muscles, the objective evidence of which can be seen kinematographically. Atkinson and Shepherd (Atkinson 1961) have previously presented evidence of muscular incoordination in T.M.J. dysfunction and have recorded it kinematographically.

Electromyographic evidence of abnormal muscular activity in these conditions has also been reported. Moreover it has been known for a long time that deviations of the mandible in opening and closing from and to the tooth position are signs of T.M.J. dysfunction. However, kinematographic evidence shows beyond reasonable doubt that T.M.J. dysfunction and its sequelae, reflex or local, are due to untreated mandibular displacements. It further indicates that muscular tensions are not per se the cause of these conditions, but may however precipitate them, in other words cause a potentially pathological condition to become pathological. Unfortunately mandibular displacements are often perpetuated in the edentulous patient and the resultant physical and psychological damage cannot be overestimated. Mandibular kinematography is an adjunct in the detection of these conditions prior to breakdown. It is also valuable in that the graphs indicate the method of treatment and check the success of treatment. It should be of value in all phases of dentistry because by it mandibular maxillary relationships may be assessed and the state of the masticatory proprioceptive mechanisms evaluated.

It would seem that maintenance of intact masticatory proprioceptive mechanisms is of supreme importance to the organism since the mesencephalic nucleus of the fifth nerve is anatomically dominant over other skeletal proprioceptive mechanisms. Its connections with cranial motor nuclei are direct and its connections with the reticular formation of the medulla and mesencephalon (Griffin 1962) indicate that disturbances of this nucleus can affect other remote reflexes (King 1955). Neurovascular and proprioceptive reflexes are intimately related and interdependent and it is hard to conceive one acting without the other. The exquisite coordination of muscular and vascular mechanisms indicates an extreme delicacy of the neural apparatus subserving its requirements and a disturbance of this system by unwarranted inputs from a disturbed masticatory system at a mesencephalic level may have far-reaching and untoward effects upon the organism.

Mongini studied masticatory function in 8 subjects with good function and 8 subjects with dysfunction. He found statistically significant differences between mandibular movements in the normal versus abnormal group.

Mongini, F. A graphic and statistical analysis of the chewing movements in function and dysfunction. The J. of Cranio. Pract. Vol 2, No. 2, March-May 1984.

ABSTRACT

To study the statistical differences between functional and dysfunctional chewing, the authors selected two groups of 8 subjects each. Group 1 consisted of subjects who had good masticatory function, while Group 2 was made up of subjects with dysfunction of the stomatognathic system. Each of the subjects was given the same amount of crispy bread and was asked to chew it normally. The subjects' mandibular movements were recorded with an Electrogonograph which was connected to an XY chart recorder and a computer. The software produced data of the mean mandibular displacement on the frontal and the sagittal planes at 20 different degrees of jaw separation. Information on standard deviation values (i.e., the repetition or variability of movements) and on velocity was also obtained. Statistically significant differences were found between the movements of Group 1 and Group 2, which allowed the authors to assess some of the parameters typical of functional chewing.

RESEARCH

In recent years, chewing movements have been investigated by several different authors. They have used methods such as cineradiography (Modica 1968, Modica 1969, Hedegard 1970), photoelectric devices or light-emitting diodes (Gillings 1967, Gillings 1973, Waysenson 1977, Karlsson 1977, Jemt 1979, Graf 1982), implanted radionuclides (Salomon 1979), and many others. Some investigations have used a sophisticated device that allows mandibular movements to be precisely recorded on tape. These can then be processed by a computer and reproduced on mandibular casts by means of a slow-speed playback device (Gibbs 1966, Gibbs 1969, Gibbs 1971, Gibbs 1982).

For this reason, we developed a computer-based system that was used to study both normal subjects and patients with dysfunction of the stomatognathic system. The purpose of this article is to describe the methods we used and to discuss the results obtained in our study.

RESULTS

The chewing movements of the subjects with good function (Group 1) showed a typical pattern when viewed on the chart recorder. On the frontal plane, the most extreme movements defined a symmetrical shape. We found this was true even when the subject had a preferred side for mastication; in such cases, although most chewing movements occurred only on one side, some symmetrical chewing strokes occurred on the opposite side as well.

DISCUSSION

The data at hand provided us with a good basis for assessing the statistical significance of the chewing movements of subjects with good function as well as of those with dysfunction of the stomatognathic system. We found the following patterns to be typical for functional chewing:

1. The opening movement tracks a rather repetitive path that shows little displacement from the mid-sagittal plane and runs parallel to it.
2. The closing stroke is concave towards the mid-sagittal plane, and the maximum speed is reached in the middle third of the path, usually just before the halfpoint is reached. This closing stroke is fairly variable, and movements become gradually less extended while the bolus is being chewed.
3. Even with subjects who have a preferred mastication side, closing movements occur on both sides, and they tend to be symmetrical.
4. On the sagittal plane, both opening and closing movements are fairly repetitive. Posterior displacement increases as the degree of jaw separation increases, and the closing stroke is located posterior to the opening movement. Anterior displacement rarely occurs, and then only at a small degree of jaw separation.
5. The velocity is high, with maximum values occurring in the middle third of the opening movement and in the first half of the closing movement.

Single figures can obviously vary considerably among the different nondysfunction subjects, but the similarity of the patterns that are presented is suggestive of standard movements.

However, when the data gathered from several dysfunction patients are compared, we can see that the differences between these subjects are striking. The patterns that we have just described as typical for good function are altered or even absent in these patients. We can assume with reasonable certainty that the number of patterns considered normal decreases as the degree of dysfunction increases. However, further investigations are needed to confirm this idea.

Ow, et al, used optoelectric tracking to analyze jaw movement in six subjects before and after treatment for craniomandibular disorders. Findings showed significant changes in velocity and duration of the chewing stroke after treatment. The authors conclude that increase in chewing rhythmicity was correlated to decrease in patient symptoms.

Ow, R.K.K., Carlsson, G.E., and Jemt, T. Craniomandibular disorders and masticatory mandibular movements. J. of Craniomandib. Disord.: Facial & Oral Pain. 1988; Vol 2, No. 2:96-100.

A subgroup of six women aged 21 to 39 years were studied for their responses to treatment for craniomandibular disorders of neuromuscular origin. Severe clinical symptoms were ameliorated over a 5- to 8-week period. A standardized recording of their chewing movements in response to treatment was done with an optoelectronic measuring system. Comparison of chewing cycle variables, before treatment began, with those obtained after the 5- to 8-week period of treatment showed that changes in speed and duration of the opening stroke in comminution were indirect indicators of recovery from dysfunctional symptoms in the masticatory system. These two parameters effected a significant change in the overall rhythmicity of chewing for these subjects. (J Craniomandib Disord 1988;2:96-100).

The purpose of this study was to determine if the results of conservative treatment for a selected subgroup of patients with CMD of neuromuscular origin (or myofascial pain-dysfunction syndrome) could be shown to influence their chewing cycle pattern.

Statistical Analysis: Analysis, by using the paired *t* test, was performed for the group of subjects. Statistically significant differences were highlighted and the level used was $P < 0.05$. If $P > 0.05$, the difference was designated NS (not significant). The coefficient of variation (CV) was used as a measure to describe the amount of variation in the sample.

RESULTS

Chewing Variables- -Rhythm, Speed, Displacement, and Area. The overall duration of a chewing cycle (rhythm) comprised an opening phase, a closing phase, and an occlusal phase. For the six subjects, the opening phase was significantly shortened from 0.18 seconds to 0.17 seconds ($P < 0.05$). The overall cycle duration (rhythm) was also reduced significantly from 0.55 seconds to 0.52 seconds ($P < 0.05$). The closing phase and occlusal phase of the chewing cycles recorded no significant changes.

The mean opening speed of the mandible in chewing was increased significantly from 65.35 mm/s to 73.45 mm/s ($P = 0.05$) after the 5- to 8-week period of treatment. The mean closing speed and the maximum speed of the mandible showed higher values, but these were not significant.

Mandibular displacement in chewing was reflected by the length of the opening stroke, the length of the closing stroke, the maximum lateral distance, the maximum vertical distance in a cycle, and the amplitude (square root of the sum of the squares of the maximum lateral and vertical cycle distances). Mandibular displacements were seen to increase, but not significantly.

The enclosed area of the chewing cycle was measured in the frontal plane, the sagittal plane and the horizontal plane. There were not significant results shown, but the frontal and sagittal loop areas increased.

DISCUSSION

The subgroup of six women, aged 21 years to 39 years, corresponded to the clinical material of CMD seen in most studies. (Mejersjo 1983, Dahlstrom 1982, Magnusson 1978) They responded fairly well to conservative treatment over the period of 5 to 8 weeks. Both signs and symptoms of CMD were ameliorated, and the frequency of headaches diminished.

The tenderness of the masticatory muscles on palpation was reduced in intensity and location with treatment. Other symptoms were mandibular deviation in opening, tenderness over the temporomandibular joint area, and movements of the mandible that were associated with pain. These latter symptoms abated at the 5- to 8-week period of treatment.

The overall duration of the chewing cycle of the six subjects was significantly shortened. The opening phase of the chew was also slightly but significantly shortened. These were interpreted as responses in the chewing cycle to the interim effects of treatment of muscular dysfunction. Other studies (Atkinson 1961, Stohler 1985) have shown irregularities in chewing rhythm for patients with similar disorders, but did not show how these were affected by treatment. The opening speed of the mandible after treatment was significantly increased for the six subjects. It appears reasonable to deduce that changes to the speed and the duration of the opening stroke have significantly affected the overall duration or rhythm of comminution.

The lateral pterygoid muscles, particularly their inferior head, and the fibers of the digastric muscles are known to be active in opening mandibular movements. (Wood 1987) It is believed that their main action is in ballistic mandibular opening. (Jemt 1984, Carlsoo 1956, Ahlgren 1966) The effects of muscular dysfunction and of treatment could perhaps be seen more clearly in the opening movement of the mandible, since muscle activity is not apparently complicated by antagonistic muscle control. (Jemt 1984, Wood 1987).

Recovery of subjects having pain and dysfunction of the masticatory system could be seen when masticatory muscle hyperactivity was effectively controlled by appropriate treatment. (Thomson, H., 1975, Mejersjo 1984, Kopp 1979, Dahlstrom 1985, Carlsson 1985) An increased overall cycle rhythm could indirectly indicate a return to normal tonicity and smooth reciprocal activity of the muscles that govern mandibular movements. The results of our study verify that successful treatment not only reduces pain and dysfunction, but also leads to a normalization of masticatory function.

STUDIES THAT DOCUMENT THE CLINICAL EFFICACY AND VALIDITY OF
MANDIBULAR TRACKING

Jankelson systematically describes the rationale and protocol for using mandibular tracking for diagnosis and treatment of orthodontic patients. The use of mandibular tracking as an adjunct to cephalometrics for orthopedically aligning the mandible to the cranium is a valuable objective quantitative technique.

Jankelson, B. Three dimensional orthodontic diagnosis and treatment a neuromuscular approach. J. of Clinical Orthodontics. Vol. XVIII, No. 9, Sept. 1984.

The use of electronically derived measurements and objective, quantitative data to diagnose the functional status of the musculoskeletal system of the head and neck is a significant step forward in the evolution of orthodontics into a major orthopedic specialty.

Musculoskeletal dysfunction of the head and neck is often the primary etiology of a diverse group of symptoms such as TMJ dysfunction, headaches, myalgia, otalgia, cervicalgia, and neuralgias. (Cooper and Rabuzzi, 1984; Jankelson, Dent Clinics 1979; Jankelson, mt Prosth Cong 'Cluster' 1979; Jankelson, 1972; Principato, 1982; DeBaisi and Neironi, 1982; Dinham, 1970; Gernet et al, 1980; Vesanen and Vesanen, 1973; Weiss, 1976; Wessbert et al, 1981; Bazzoti, 1983; Choi and Mitani, 1973; Schwartz, 1955; Thompson, 1971; Carlsson, 1981; Reik and Hale, 1981; Farrar, 1979; Gelb et al, 1978; DeSteno, 1977; Laskin, 1969; Mikhail and Rosen, 1980; Burton, 1969). Before beginning treatment, the orthodontist should consider musculoskeletal dysfunction as a possible cause of one or more of these symptoms or as a presymptomatic potential for future dysfunction (Cooper and Rabuzzi, 1984; Jankelson, 1982). Today's superior diagnostic capabilities can uncover and intercept presymptomatic musculoskeletal disease that could become acute and symptomatic under the added stress of orthodontic procedures.

Measurement for the diagnosis of existing musculoskeletal dysfunction in the orthodontic patient provides a needed additional functional diagnosis to complement the conventional use of cephalometric and TMJ x-rays. The electromyograph (EM2) and mandibular kinesiograph (MKG) respectively measure electrical activity of the muscles and the skeletal relation of the mandible to the skull. These data are essential for initial diagnosis, monitoring of treatment progress, and verification that a relaxed neuromuscular environment- -which is the goal of functional orthodontic treatment- -has been obtained for the finished case.

SUMMARY

Improvement of appearance is a primary motivation for patients seeking orthodontic treatment. However, every orthodontic patient is also a neuromuscular patient. Alleviation of the head and neck pain of musculoskeletal dysfunction must become an equally strong motivation for orthodontic care, as health-care professionals and the public become increasingly aware of its effectiveness and availability.

It is essential in the diagnosis of every patient, before instituting therapy, to derive precise, quantitative data that reveal whether the skeletal relation of the mandible to the skull is distorted or not, and document the extent of musculoskeletal dysfunction of the head and neck stemming from an existing malpositioned occlusion.

Structural diagnosis based on cephalometric and other x-rays gains in significance when supported by functional data of musculoskeletal status. The increasing emphasis on the orthopedic correction of skeletal malrelation of the mandible to the skull inevitably expands the scope and changes the image of orthodontic practice. As EMG and MKG data show, the significance of the orthopedic capability of orthodontics extends beyond the jaws along to the entire musculoskeletal system of the head and neck; and, as functional considerations become paramount, the orthodontist becomes the primary orthopedic specialist in treatment of head and neck pain.

Callender discusses the rationale and protocol of integrating mandibular tracking into traditional diagnostic techniques. Pre and post treatment evaluation of orthodontic and TMJ problems utilizing mandibular tracking provides a more predictable, functional and stable result.

Callender, J.M. Orthodontic application of the Mandibular Kinesiograph: Part II. J. of Clinical Orthodontics, Vol XVIII, No. 11, pp 791-805, Nov. 1984.

CONCLUSION

This series of articles has introduced a concept of treating orthodontic cases in the vertical dimension to a determined rest-to-closure distance, with the occlusion set on a pathway on which the jaws are free to open and close without encumbrance and with relaxed musculature. This position is often at variance with existing dentric occlusion or with a centric relation achieved by the most distal positioning of the condyles. It is a stable post-treatment position, at which the condyles are well centered in the fossae.

This treatment does not discount current orthodontic concepts. It uses an additional diagnostic tool- -the MKG- -which allows visualization of the functioning jaws, and it cross-references this data with that of traditional orthodontic diagnostic techniques.

All the traditional orthodontic treatment modalities, along with the new concepts in functional appliances, are used to resolve functional problems. Functional appliances are fabricated to the jaw position indicated by the MKG. We have been able to create occlusions and jaw functions that are dramatically more free of pathology-producing dysfunction, and that have remained free of dysfunction for a number of years. The MKG is also used post-treatment to assure that functional goals have been achieved. Continued evaluation of completed cases demonstrates that the MKG-dictated resolution of orthodontic problems and TMJ dysfunction is efficient, stable, and economically viable.

Callender discusses the rationale and protocol of integrating mandibular tracking into traditional diagnostic techniques. Pre and post treatment evaluation of orthodontic and TMJ problems utilizing mandibular tracking provides a more predictable, functional and stable result.

Callender, J.M. Orthodontic application of the Mandibular Kinesiograph: Part L. J. of Clinical Orthodontics. Vol XVIII, No. 10, pp 710-718, Oct 1984.

In our office, in addition to standard orthodontic records and tomograms, we do a mandibular kinesiograph (MKG) analysis on patients who present any of the following symptoms:

- * Joint noise or encumbered opening and closing of the jaws
- * Pain to palpation of the joint capsule and several muscles of mastication
- * Chronic ear problems
- * Poor rate of opening and closing the jaws
- * Diminished range of motion of the jaw (in three dimensions)
- * Various crossbites or septal midline asymmetries
- * Various tongue-swallow dysfunctions
- * Various airway problems
- * Apparent skeletal disproportions of the jaws
- * Various facial asymmetries

PRETREATMENT FUNCTIONAL ANALYSIS

Pretreatment jaw function is analyzed by recording typical jaw motions on the cathoderay screen. To understand abnormal MKG tracings, it is necessary to know the appearance of normal tracings.

The greatest value of an MKG is that it gives the operator electronically magnified eyes to view the stomatognathic system in function. As the operator gains experience, he can develop hypotheses for resolving dysfunction and observe their validity 'live' prior to pursuing irreversible treatment procedures.

INITIAL ANALYSIS

The initial analysis of jaw function is made using these photographs together with study casts and pantographic, cephalometric, and tomographic x-rays. Hypotheses can be tested by observing the screen as the patient performs various jaw functions- - swallow, speech sounds, maximum opening and closing, stretch reflex, etc. Plans must be made to eliminate contributors to abnormal jaw function.

We often find it necessary to use a splint to negate proprioceptive influences. Psychic input that is affecting jaw function can also be evaluated.

In my experience, very few young people have suffered pathologic alteration of the mandibular condyle, meniscus, or temporal fossa. It is common for them to have clicks and pops associated with entrapment of function of the joint parts. These alterations of joint function can be observed and measured on the MKG screen. They often can be correlated with abnormal positions of the condyle in the temporal fossa at centric or during translation of the joint as observed in tomograms. Their resolution should be planned during this analysis.

RECORDING MYOCENTRIC

After carefully analyzing all the factors involved- -joint condition, swallow reflex, airway, occlusion, etc. - - the doctor marks a point on the screen where he wants the jaw to be positioned. A photograph of the screen is made at this point, which reflects the condition of the musculature and the quality of muscle function at the time of registration.

The technician then makes the acrylic index of that jaw position, and marks on the photograph the precise point at which the patient was directed during registration.

A point 1.5mm above physiologic rest is chosen to record the bite index. This is to be the eventual myocentric. The index is used for mounting one set of casts to be used during diagnosis. We routinely index within 0.25mm of our chosen point on the screen in all three planes of space. In cases of reciprocal click, it is extremely important that the point of index be on the path of closure at more jaw opening than the point of reciprocal click. We want to be sure the meniscus is recaptured by the condyle, and not displaced. This takes precedence over initially achieving myocentric, and it must be documented in the records to avoid confusion later on.

TREATMENT PLANNING

Information for treatment planning includes the patient's history, range of motion, and muscle palpation charts that are completed at the initial examination. All x-rays- -including tomograms of the joints- -are arranged for viewing on a large medical viewer so that they may be cross-referenced. Two sets of models are used- -one set oriented to the existing occlusion in the traditional orthodontic manner, and the other mounted on a Galetti articulator, using the MKG indices.

The notes made while observing the patient on the MKG screen and the photographs of the screen are also important, because they document the initial problems and qualify the MKG indices. The initial MKG index does not always represent the myocentric that we are trying to achieve. Although it is taken with the jaws closing on the trajectory dictated by the relaxed musculature, there are sometimes vertical interferences such as division 2 anterior tooth interference, tongue volume, airway demands, and collapsed dental arches with complicated occlusal schemes. The intention is to plan initial treatment with the best jaw position possible.

We use any procedure needed to achieve an unencumbered path of opening and closing of the jaws as demonstrated on the MKG, and we are careful that we have achieved myocentric before final treatment is planned.

Once a trustworthy MKG index is achieved, final treatment planning is undertaken to resolve the orthopedic and orthodontic problems. The concept is to treat to an MKG-defined jaw position and not to an existing centric occlusion. Incipient pathology may already be present in the joints.

George and Boone used the MKG to study vertical dimension of rest position and mandibular closure to maximum intercuspation of the teeth. The many potentials for clinical use of the MKG for mandibular tracking are clearly brought forth.

The investigation also showed “that the Myo-monitor does relax musculature to a highly significant degree.” Again, the thesis that lowered postural activity is a desired biofeedback objective would validate the Myo-monitor as a modality contributing to the clinical objective. Therefore, if the preliminary committee draft statement “As a treatment tool, EMG has been and is being used in conjunction with relaxation and biofeedback therapy” is clinically valid, this controlled study documents the efficacy of the Myo-monitor to achieve the same physiologic result. To regard the relaxation tool of the dentist, i.e. Myo-monitor, as being not clinically acceptable while the tool of the psychologist is recognized is antithetical to honest scientific inquiry. If relaxation is a valid clinical objective for biofeedback, it is a valid clinical objective for the dentist responsible for occlusal therapy.

George, J.P. and Boone, M.E. A clinical study of rest position using the Kinesiograph and Myo-monitor. The Journal of Prosthetic Dentistry. Vol. 41, No. 4, pp 456-462, April 1979.

However, rest position and closure through interocclusal distance represent a physiologic three-dimensional occurrence in space. The muscles involved are not just the elevators of the mandible. There are also the prime movers, the antagonists, and the synergistic muscles that help stabilize the movement. Muscle contraction also depends on the metabolic condition of the fibers, since contraction depends on the ability of the muscle tissue to use and resynthesize high-energy phosphate compounds in the presence of minerals, particularly calcium and magnesium. Proper nutrition and metabolic balance are necessary for the efficiency of this system (Anthony, C.P. and Kolthoff, N.C. 1975; Montgomery, R., Dryer, R.L., Conway, T.W., and Spector, A.A. 1977). Furthermore, numerous studies (Vig, P.S., and Hewitt, A.B. 1975; Mulick, J.F. 1965) have shown that skeletal facial asymmetry is prevalent in most persons, emphasizing the importance of measuring the three dimensions of the vertical dimension of rest position.

Until recently the instrumentation for three-dimensional measurements has not been available. This study was designed to show rest position and closure through the interocclusal distance in three-dimensions; and an electronic instrument, the mandibular Kinesiograph, was used (Jankelson, B., Swain, C.W., Crane, P.F., and Radke, J.C. 1975). The Kinesiograph is able to measure the mandible as it moves freely or during tooth contact in the frontal, sagittal, and horizontal planes simultaneously. The study was also designed to show rest position and closure before, during, and after muscle relaxation.

The Myo-monitor (Jankelson, B. 1969) was used to relax the musculature by a light myopulse induced electronically. The Myo-monitor was used because of the claim that **it** can relax musculature. Studies have shown that repeated electrical stimulation increases the potential of the electrical output of the muscles and that short, rhythmic muscle contractions enhance muscle blood flow and therefore nutritional enrichment (Dixon, H.H., O’Hara, M., and Peterson, R.D. 1967; Selkurt, E.E. 1971).

The present investigation was designed to help the dentist visualize mandibular movement as three dimensional and appreciate the variability of the postural position as a necessary physiologic entity. The usefulness of measurement by the mandibular Kinesiograph and the effectiveness of the Myo-monitor as a muscle-relaxing tool will be described.

METHODS AND MATERIALS

The 14 subjects used in the study included four women and 10 men ranging from 21 to 50 years of age

RESULTS

Tracings and the points of measurement of the mandibular movement obtained from the Kinesiograph are shown in Figs. 3, 4 and 5. Measurements were made of the vertical dimension of rest position to closure into centric occlusion before, during, and after stimulation by the Myo-monitor.

Clinical data were analyzed for vertical, anteroposterior, and lateral components of movement using the factorial analysis of variance with repeat measures design (Winer, B.J. 1962). T-tests were used to determine the significance of movement in the lateral component. Differences between positions and between days for the vertical component of movement are recorded in Table I, which shows a significant difference between positions ($F = 38.08, p < .001$) regardless of the day the measurement was made.

The three positions over the three days were subjected to the Newman-Keuls sequential range test (Winer, B.J. 1962) for multiple comparisons. All pairwise comparisons were significant at the .01 probability level. Position 3 showed greater mean values than either position 1 or position 4. Position 1 showed the smallest mean value.

The data for the factorial analysis of variance between positions and days for the anteroposterior component of movement are shown in Table III. There was no significant difference between either days or positions. The F values for the anteroposterior component were the lowest of all those for the three movements.

Factorial analyses of variance on the data between positions and days for the lateral component of movement are shown in Table IV. There was no significant difference between either days or position. The F value between positions had the highest value, which was not considered significant since the probability level is between .05 and .10.

The data for the lateral component of movement were subjected to t-tests to detect the significance of lateral movement (Table V). No movement was assumed to be zero, so that t-tests statistically tested the presence of lateral movement. There was a difference at the .05 level in position 1 on all three days, in position 4 for the last two days, and in position 3 for the last day. An important finding was a consistent lateral component of movement prior to Myo-monitor stimulation.

DISCUSSION

The results of the investigation of vertical movements show that the Myomonitor does relax musculature to a highly significant degree. During the Myomonitor relaxation procedure, the facial muscles, along with the masticatory muscles, were subjected to myo-pulse exercise. This may have been the reason for the greater interocclusal distance. The finding of greater interocclusal distance during relaxation is consistent with Griffiths' (1975) finding of increased interocclusal distance during sleep. Griffiths, who studied only vertical movement, attributed the increased distance partially to relaxation of the facial musculature.

In this study, regardless of differences in the vertical position within the rest position range, there were no significant differences in anteroposterior or lateral movements. These findings mean that the mandible dropped inferiorly in the resting range. This inferior movement means a changing of the rotational axis. Closure, then, would be around a changing axis. Since the mandible is suspended, it should be considered a definite possibility that the rotational axis does change during function.

An increase in vertical distance without significant anterior or posterior movements could be due to relaxation of the facial musculature, but it must be accompanied by or result in inferior movement of the mandible, not in movement which would describe an arc around a fixed condylar axis.

Results of the lateral component of movement showed that there was no significant difference in position before, during, or after relaxation procedures or between sittings. In previous studies of rest position the lateral component of movement has received scant attention, and no quantitative study is known to exist. For this reason, position No. 2, the myo-pulse movement, was also included in the statistical data, and the lateral component of movement was compared to zero movement by t-tests. Differences were found to be significant, particularly before relaxation. A review of the literature involving facial asymmetry shows that this should be no surprise. In a radiographic study of subjects with no clinical evidence of unacceptable facial asymmetry or gross deviation of dental arrangement, Vig and Hewitt agreed with earlier studies (Burke, P.H. 1971; Mulick, J.F. 1965) in reporting that there was an overall facial asymmetry. More study is needed to determine how this deviation relates to deviation on maximum opening.

If the rotational axis changes, a muscular adjustment would be expected prior to closure, which positions and alerts the musculature. As a supplement to this adjustment, or as a substitute for it, there may be a "directional adjustment" which serves as a guide to closure when tooth contact occurs. This adjustment would occur in all three planes.

Figs. 6 and 7 show this phenomenon, and it can be seen in most tracings. Muscle length may vary, depending upon the stress within the system, and variability of the vertical dimension of rest position seems necessary to accommodate tension or relaxation in the musculature; therefore the cuspal slopes of teeth may act as the final guide to closure. This interpretation is supported by Posselt's (1968) three-dimensional diagram of the envelope of motion, which shows maximum intercuspation to be the point of a pyramid.

A question arises as to the accuracy of the Kinesiographic representation of movement. The Kinesiograph has been reported to have an accuracy of 0.1 mm for the resolution of mandibular position in the vicinity of occlusion. At a vertical opening of 20 mm the geometric error is -3% in the vertical, +5.7% in the anteroposterior, and 0 in the lateral component. If at 20 mm of vertical opening the mandible is moved either to the left or to the right 10 mm, then a -6% error would occur in the lateral component, so that a 9.4 mm lateral reading would be shown on the cathode ray tube.

Since measurement in this study did not deviate from the null point of occlusion more than 5.5 mm, and since this was a comparative study, no effort was made to make a correction to absolute data. However, a computer program could be designed to accomplish this correction.

One other variable that could influence the accuracy of the study was head position of the subjects. No restrictive headrest was devised because of its possible effect on the relaxation of the musculature. However, head position was monitored visually. Head position could possibly be monitored electronically with the aid of a sensor that could detect variation from a predetermined position.

Patients devoid of neuromuscular symptoms were purposely selected to establish some norm for future studies. Future studies could include subjects with neuromuscular problems. The vertical dimension of rest position could also be studied with reference to centric relation in asymptomatic patients.

SUMMARY

This clinical study was designed to study the vertical dimension of rest position and mandibular closure to maximum intercuspation of the teeth before, during, and after relaxation procedures on 14 subjects with stable dentitions. The findings call attention to the potential of both the Myo-monitor and the Kinesiograph for research and clinical use, to the physiologic need for flexibility of the vertical dimension of rest position, and to the importance of measuring all three dimensions when examining the rest position.

Konchak, et al, evaluate before and after TENS mandibular position correlating SN/mandibular plane angle and clinical freeway space. The study concluded that the S-N/MP angle did not prove to be a reliable predictor of freeway space. However, the authors point out that both clinical rest position and physiologic rest position can be differentiated using the Myo-monitor and Mandibular Kinesiograph.

Konchak, P.A., Thomas, N.R., Lanigan, D.T., and Devon, R. Vertical dimension freeway space, a kinesiographic study. *The Angle Orthodontist*. pp 145-154. April 1987.

Fujii (1977) and Godaux and Desmedt (1975) demonstrated that transcutaneous stimulation produced deconditioning of musculature by reducing muscle spindle feedback. The proprioceptive disfacilitation following TENS has been explained by antidromic block via the fifth cranial nerve motor fibers (Hoffman 1918, Magladery 1955, Homma 1959), inhibition by upper motor neurons on the motor nucleus of the trigeminal nerve (Teasdall et al. 1952), and deactivation of the gamma motor neuron drive to the muscle spindles (Valibo 1971).

The muscle relaxation that results from TENS-induced proprioceptive disfacilitation of the fifth motor neurons is not a fatigue phenomenon, as is shown by the heightened masticatory muscle force following TENS, the elevated maximal velocity of jaw closure, and the increased integrated electromyographic activity of the masticatory musculature during clenching.

The proprioceptive disfacilitation is sustained as long as the teeth are not brought into occlusion and TENS is maintained (Jankelson and Radke 1978). Fujii (1977) has found that the proprioceptive disfacilitation is released at a slightly longer interval than 80-95msec, a time that is clearly not indicative of a fatigue phenomenon.

Wessberg (Wessberg and Epker 1981, 1983, Wessberg et al. 1981, 1982) has defined “clinical” and “physiological” rest positions of the mandible that appear to correspond to Jankelson’s “adaptive” and “true” rest positions of the mandible. Rugh and Drago (1981) studied rest position and jaw muscle activity using EMG and the kinesiograph and reported that clinical rest position is accompanied by muscular activity. Yemm and Berry (1969) conclude that mandibular rest position is largely governed by an equilibrium of elastic forces when the subject is fully relaxed and muscle activity is not fundamental to the posture

RESULTS

The subjects were arranged into the three groups in order of increasing SN/MP angle and the mean values for “adaptive” and “true” freeway spaces calculated (Table 1). Differences between the pre- and poststimulation measurements were seen to both increase and decrease with respect to the adaptive freeway space measurement, although the mean difference for each group was seen to be positive (Fig. 3).

The overall mean “adaptive” and “true” freeway spaces for the 25 subjects in the study was 1.8mm and 2.9mm respectively. An analysis of variance to compare the “adaptive” and “true” freeway spaces of these subjects showed a significant increase in freeway space following transcutaneous electrical nerve stimulation ($F(1,24)=7.625$) ($.01 < P < .02$).

This statistical test also revealed that subject variation was significant, indicating that not all subjects reacted in the same manner to the electrical stimulation ($F(24,25)=2.64$) ($.01 < P < .02$).

An analysis of variance was also performed to learn whether low (<25o) S-N/MP angle subjects behave differently from medium (25-38o) and high (>38o) S- N/MP angle subjects. The results demonstrate no significant variation among these groups, although the sample size of this study may be too small to detect some statistical differences.

Linear regressions were performed to determine whether there was any correlation between the S-N/MP angle and the “adaptive” and “true” freeway spaces. These demonstrated that there was a significant negative correlation between “adaptive” freeway space and S-N/MP, with 34.5% of the variation in freeway space being accounted for by the S-N/MP angle ($r=0.587$; slope=-3.34 and intercept=37.49 (Fig. 4).

The “true” freeway space, however, did not correlate with the S-N/MP angle, with only 1% of the variation in freeway space accounted for by total variation in the S-N/MP angle ($r=0.1066$; slope=-0.35 and intercept=32.31) (Fig. 5).

DISCUSSION

The desirability and validity of using freeway space measurements in dentistry has been widely debated. Silverman (1957) criticized principles and techniques based on rest position and freeway space as “the greatest single cause of so much confusion of maxillo-mandibular relations”. Atwood (1956) and Olsen (1951), using cephalometrics, showed that freeway space was not an accurate procedure. In their studies, measurements were made before and after loss of the dentition, with dentures in and out of the mouth, at the same and at different sittings. Freeway space measurement varied in the same patients.

One possible reason for this uncertainty is that the various clinicians and researchers are often discussing and evaluating two separate entities - physiologic and clinical rest position, without adequately differentiating between the two. The means for measuring these two positions was also inadequate until the use of the Myo-monitor and kinesiograph enabled clinicians to accurately measure both of these positions of the mandible (Jankelson and Radke 1978, Myotronics 1977, Hannam et al. 1977, Jankelson 1980). It is only recently that researchers have begun to use this sophisticated technology to investigate freeway space.

Wessberg et al (1982) found the interocclusal distance at physiologic rest position to be inversely related to the vertical dentofacial morphology.

In this study, the “adaptive” or clinical freeway space was significantly correlated with the sella-nasion/mandibular plane angle, whereas “true” or physiologic freeway space was not. Although there was an overall mean positive increase in freeway space of 1.1mm after TENS stimulation, it should be noted that differences between freeway space before and after stimulation could be either positive or negative. If relaxation of the muscles does occur (Jankelson 1982), it does not necessarily mean that freeway space values are larger after stimulation. Relaxation of the musculature is thus not necessarily synonymous with an increase in freeway space, as it could depend upon whether the elevator or depressor muscles have been relatively more relaxed

Freeway space is a description, however limited, of a physiologic parameter of an individual patient

Wessberg, et al, used the Mandibular Kinesiograph to determine mandibular rest position induced by phonetics, TENS and integrated EMG of the masticatory muscles. The authors found that these were three distinct biologic positions that are reproducible over time. They conclude that clinical rest position and physiologic rest position provide a scientific means of measuring neuromuscular adaptation.

Wessberg, G.A., Epker, B.N., and Elliott, A.C. Comparison of mandibular rest positions induced by phonetics, transcutaneous electrical stimulation, and masticatory electromyography. The Journal of Prosthetic Dentistry. Vol. 49, No. 1, pp. 100-105, January 1983.

RESULTS

A three-way analysis of variance with one observation per cell was performed to analyze the data obtained from this investigation. The factors analyzed were experiment, treatment, and subject. This analysis revealed no experiment-by-subject interaction ($p = .24$) and no experiment-by-treatment interaction ($p = .51$), but there was a significant subject-by-treatment interaction ($p < .01$). These interactions are illustrated in Figs. 5 to 7.

Neuman-Keuls multiple comparisons were performed at the .05 significance level for subjects and experiment and for subjects and treatment. These comparisons found no significant difference in mean response for subjects across experiment. These comparisons also showed that treatments PRPM-TES and PRPMEMG are not significantly different and that both yield higher mean responses (greater IOD) than the CRPM (phonetic) treatment.

DISCUSSION

The results of this investigation of mandibular rest position induced by phonetics, TENS, and integrated masticatory EMG in four adult women with normal dentofacial morphology were significant in several aspects. Primary among these findings is the fact that the three mandibular rest positions are biologically distinct entities that are reproducible across time. The data obtained in this study demonstrated the mean IOD at the CRPM (phonetics) to be $2.5 + 1.2$ mm and at the PRPM to be $5.2 + 1.5$ mm (TES) and $5.3 + 1.9$ mm (EMG).

The second important feature of this investigation is the fact that PRPMs induced by TES and minimum integrated masticatory EMG were not statistically different. In essence the determination of the PRPM can be induced reproducibly by either TES or minimum integrated masticatory EMG activity.

The findings of this investigation are relevant to clinical research involving the stomatognathic system. The CRPM and PRPM may now be employed to measure the effects of prosthodontic, orthodontic, and orthognathic surgical procedures that significantly alter the occlusal vertical dimension. Specifically, pretreatment and posttreatment measurements of the CRPMs and PRPMs in individuals who undergo prosthodontic or orthodontic procedures that significantly “open the bite” (increase occlusal vertical dimension) or orthognathic surgical procedures that reposition the maxillae superiorly or inferiorly will reveal the subsequent neuromuscular adaptations that occur within the stomatognathic system.

SUMMARY AND CONCLUSION

Four adult women subjects with normal dentofacial morphology and a complete dentition were employed to compare the IOD at the mandibular rest positions induced by phonetics, TES, and minimum integrated masticatory EMG (treatments). A mandibular kinesiographic instrument that had been tested for reliability was used as a biologically compatible instrument for the measurement of the IOD at the four weekly experiments. A three-way analysis of variance and Neuman-Keuls multiple comparisons revealed that the three mandibular rest positions studied were reproducible within a specific subject at various time intervals. In addition, IOD at the CRPM (2.5 mm) was significantly less than the IOD at the PRPM, whether induced by TES (5.2 mm) or minimal integrated masticatory EMG activity (5.3 mm). Therefore, it is apparent from this study that the CRPMs and PRPMs provide a scientific means of measuring neuromuscular adaptation to major prosthodontic, orthodontic, and orthognathic surgical procedures.

Crandall presents an overview of techniques and procedures for evaluating mandibular range of motion in dysfunction patients. The Mandibular Kinesiograph is described as an excellent tool for evaluating both mandibular velocity and movement in three spatial planes.

Crandall, J.A., Evaluation of mandibular movement and range of motion in the diagnosis of craniomandibular disorders. J. of Craniomandib Pract. July 1986, Vol 4, No. 3, pp 234-245.

Dental literature contains a great deal of information on the examination and diagnosis of craniomandibular disorders. Examination of mandibular movement and range of motion can be particularly helpful in obtaining an accurate diagnosis of these disorders.

Mandibular range of motion, as described by Posselt, (Posselt 1968) refers to the objective measurement of the extreme limits of movement in the envelope of motion. Mandibular movement describes the character or quality of the motion required to reach these limits. This article will present a method of recording this information and will propose possible diagnoses based on the results obtained from this examination.

RECORD OF MANDIBULAR RANGE OF MOTION

Pantographic tracings may be taken to provide a permanent record of lateral and protrusive mandibular range of motion. Study models may be mounted on a fully adjustable articulator and the pantographic recordings used to establish the protrusive condylar path, the vertical axis, the mandibular side shift, the terminal hinge axis, and so forth. (Guichet 1977) However, the value of this technique as a diagnostic tool for craniomandibular disorders is limited, and it is impractical to use on every patient complaining of TMJ dysfunction. Its primary purpose is “to diagnose the posterior determinants of mandibular movements (temporomandibular joint characteristics) and to effect a face bow transfer of the maxillary cast” (Guichet 1977) to an articulator for restorative evaluation and fabrication of prostheses.

The Mandibular Kinesiograph is an excellent tool for observing and recording mandibular movements in all three spatial planes. (Jankelson 1980, Hannam, De Cou, et al. 1980) Tracings taken with the patient chewing food provide information about functional or masticatory movements of the mandible. This equipment can also be used to record the range of motion. However, this is an expensive instrument and requires special training in its use. Cost-effectiveness may be a consideration

RECORD OF MANDIBULAR MOVEMENT

Another consideration is the velocity of mandibular movements. (Cooper, B.C. and Rabuzzi, D., 1984) Bradykinesic (slow) and dyskinesic (irregular) mandibular movements are strongly suggestive of restricted function of the craniomandibular complex. Normal movement consists of rapid, uninterrupted acceleration and then deceleration from start to finish. Appropriate treatment will in many instances reduce or eliminate the various types of inhibited movement that accompany craniomandibular dysfunction. The Mandibular Kinesiograph is an excellent tool for evaluation of the mandibular velocity. This instrument can graphically demonstrate the dramatic decrease in mandibular velocity that accompanies muscular dysfunction, pain inhibition, or intracapsular derangement.

In evaluating mandibular movement and range of motion to diagnose craniomandibular disorders, it is critical to keep in mind that recorded information most likely represents a combination of a number of different disorders. The purpose of this examination is to sort out these disorders and to determine the true sources of the patient’s complaint.

Other forms of craniomandibular disorders exist which cause little or no alteration of mandibular function. Problems such as muscle splinting, myositis and inflammatory arthritis do not alone produce changes in movement or range of motion. It is the inhibitory effects of pain or other associated dysfunctions in combination with these disorders that will result in changes in mandibular kinetics.

CONCLUSION

The primary intent of this paper is to present a simple, straightforward means of recording mandibular movement and range of motion. Using the procedure described above, the examiner should be able to:

1. Determine the incisal vector of deflection from the reproducible “hinge” relation (pathologic or nonpathologic) to the reproducible maximum intercuspation.
2. Visualize and record mandibular range of motion from the maximum intercuspation position in protrusion, lateral movement and maximum opening movement.

3. Evaluate the quality of movement as the mandible travels through the range of motion.
4. Use the recorded information to more precisely determine the true source of the patient's craniomandibular complaint and to establish an exact diagnosis.

Evaluation of this information in the diagnosis of craniomandibular disorders must include the following considerations:

1. Deviations from normal movement and range of motion can be used to determine the extent and character of craniomandibular dysfunction.
2. The basic changes in movement and range of motion caused by the identified disorder only.
3. Results of this examination are most likely the composite of more than one dysfunction.
4. Accurate diagnosis of craniomandibular disorders is based on the rational evaluation of as much pertinent diagnostic data as can be reasonably obtained.

Careful observation, attention to detail and the use of new, advanced techniques will aid the examiner in his or her quest to better understand the complexities of craniomandibular disorders and properly diagnose the source of the patient's complaints.

STUDIES UTILIZING MANDIBULAR TRACKING FOR RESEARCH PROTOCOLS

Belser and Hannam used mandibular tracking with EMG to examine the effect of occlusal contact on electromyographic activity of the masticatory muscles and patterns of mandibular movement. The study documented changes in muscle activity with different occlusal schemes.

Belser, U.C., and Hannam, A.G. The influence of altered working-side occlusal guidance on masticatory muscles and related jaw movement. *The Journal of Prosthetic Dentistry*. Vol. 53, No. 3, pp 406-413, March 1985.

MATERIAL AND METHODS

JAW DISPLACEMENT

Simultaneously with EMG activity, jaw displacement was monitored in three planes by means of a noninvasive electronic transducer (Kinesiograph, Myotronics Inc., Seattle, Wash.). Magnetometers carried on a light headframe sensed the movement of a small magnet cemented with self-cured acrylic resin to the labial aspect of the lower anterior teeth in the midsagittal plane. A detailed description of the kinesiographic measurement of jaw displacement has been reported (Jankelson, B., Swain, C.W., Crane, P.F., and Radke, J.C. 1975). If the instrument is properly calibrated, linearized, and combined with the adequate software, it is capable of recording incisor point movement to within 0.3 mm anywhere within the envelope of chewing (Hannam, A.G., De Cou, R.E., Scott, J.D., and Wood, W.W. 1980). The signals from the three displacement channels were related to three orthogonal planes that passed through the incisor point and included a midsagittal plane and a horizontal plane parallel to the Frankfort horizontal plane. The signals were led to the analog-to-digital converter, sampled, and stored at the same rate as the EMG data.

SUMMARY AND CONCLUSIONS

The effect of four different occlusal situations (group function, canine guidance, working side occlusal interference, and hyperbalancing occlusal interference) on EMG activity in jaw elevator muscles and related mandibular movement was investigated on 12 subjects. With a computer-based system, EMG and displacement signals were collected simultaneously during specific functional (unilateral chewing) and parafunctional tasks (mandibular gliding movements and various tooth clenching efforts) and analyzed quantitatively.

When a naturally acquired group function was temporarily and artificially changed into a dominant canine guidance, a significant general reduction of elevator muscle activity was observed when subjects exerted full isometric tooth clenching efforts in a lateral mandibular position. The original muscular coordination pattern (relative contraction from muscle to muscle) remained unaltered during this test. With respect to unilateral chewing, no significant alterations in the activity or coordination of the muscles occurred when an artificial canine guidance was introduced.

Introduction of a hyperbalancing occlusal contact caused significant alterations in muscle activity and coordination during maximal tooth clenching in a lateral mandibular position. A marked shift of temporal muscle EMG activity toward the side of the interference and unchanged bilateral activity of the two masseter muscles were observed.

The results suggest that canine-protected occlusions do not significantly alter muscle activity during mastication but significantly reduce muscle activity during parafunctional clenching. They also suggest that non-working side contacts dramatically alter the distribution of muscle activity during parafunctional clenching, and that this redistribution may affect the nature of reaction forces at the temporomandibular joints.

Konchak, et al, used sixty-two patients at the University of Saskatchewan to evaluate rest position of the mandible. The study concluded that masticatory muscle relaxation was significantly greater after TENS therapy. Comparative evaluation of adaptive and true freeway showed increased freeway space after TENS, with clinical and true freeway values inversely correlated with the S-N/MP angle.

Konchak, P., Thomas, N., Lanigan, D., and Devon, R. Freeway space measurement using mandibular Kinesiograph and EMG before and after TENS. *The Angle Orthodontist*, October, 1988, pp 343-350.

Although it is well recognized that the morphology of the craniodentofacial complex has functional influences (Schudy 1964, Sassouni 1969, Paolini 1970), the physiologic parameters influenced by morphology are still not well understood. This investigation expands on a previous pilot study (Konchak et al. 1986) concerned with the identification and correlation of certain morphometric and physiologic properties of the craniofacial complex related to mandibular rest position.

Vertical positioning of the maxillary and mandibular dentitions is dependent on the equilibrium between intrusive environmental forces and the eruptive forces of the supporting tissues acting on the teeth. This balance may be affected by a myriad of factors and variables involving bone, teeth, and soft tissues, including therapeutic efforts such as orthodontics and orthognathic surgery.

Orthodontists and maxillofacial surgeons have traditionally approached these relationships using descriptive methods based on clinical examination and cephalometric and/or dental cast analyses. As these emphasize static rather than dynamic factors, the physiology of the stomatognathic system, and in particular the neuromuscular system, often receive little attention.

A patient's resting vertical dimension, including the freeway space (FWS), is essentially an adaptive physiologic parameter (Mohl 1978, McNamara et al. 1978). Rest position has been defined as the neutral rest position attained by the mandible as it is involuntarily suspended by the reciprocal coordination of the elevator and depressor masticatory muscles with the upper and lower teeth separated (Niswonger 1934). McNamara et al. 1978 state that rest position is influenced by the activity of the fusimotor system of the elevator muscles through psychic input, and through stimuli from peripheral receptors such as those located in the temporomandibular joint, periodontal ligament, gingiva, tongue and palate:

Jankelson (1977) has described adaptive and true rest positions of the mandible, and thereby adaptive and true freeway spaces. Adaptive freeway space is defined as the interocclusal space that exists when the patient is instructed to voluntarily allow the jaw to relax. True freeway space is the interocclusal space present after relaxation of the masticatory musculature has been achieved, such as occurs following transcutaneous electrical nerve stimulation (TENS) with a myomonitor.

A relaxed muscle is defined as one that is neither contracted nor stretched (Ganong 1985). At this physiologic resting length the muscle is capable of exerting maximal force and maximal velocity under isometric and isotonic conditions respectively. This capability has been explained by the sliding filament theory of muscle contraction which postulates that the maximal availability of cross-bridge reactive sites is present at a muscle's physiologic resting length (Huxley 1969).

That masticatory muscle relaxation is achieved following transcutaneous nerve stimulation to the motor division of the trigeminal nerve is confirmed by post-TENS reduction in electromyographic activity, and by an increased muscle response in both force and velocity to electrical stimulation at threshold levels. A spectral analysis of voluntary isometric contraction reveals that fatigue is resolved and not induced by TENS. The power density spectrum frequency maximum shifts from a fatigue level of 75Hz to a relaxed level of 125Hz (Thomas 1987). Comparisons between muscle velocity, force dynamics, and electromyographic spectral analyses confirm that an electrical noise level below 15UV indicates the attainment of physiological resting condition of the masticatory musculature.

After reviewing the results of the pilot study, it was felt that a similar study should be repeated utilizing a larger sample size, and including EMG investigation. The purpose of this research project was to:

1. Determine the percentage of patients who achieved masticatory muscle relaxation following TENS stimulation.
2. Compare adaptive and true freeway spaces.
3. Correlate adaptive and true freeway space values with cephalometric parameters that describe the vertical dimension of the face and facial proportions.
4. Compare freeway space with the Angle classification.

METHODOLOGY

Sixty-two patients seen at the University of Saskatchewan for orthodontic treatment were selected for participation in the study. No criteria for selection were used except that they had to have a natural dentition and be free of symptoms suggestive of temporomandibular joint dysfunction.

Lateral cephalometric radiographs were obtained for each patient with the Frankfort plane horizontal, and with the mandible in the centric occlusion position. From these cephalographs the sellanasion / mandibular plane angle (S-N/MP) and percentage nasal height values were measured to represent common descriptive measurements of the patient's vertical dimension.

Subjects were seated in a chair and transcutaneous electrical nerve stimulation instrumentation applied utilizing the protocol established by (Jankelson 1977, Jankelson and Radke 1978 and Jankelson 1981). This consisted of the myomonitor, mandibular kinesiograph (MKG) (Myotronics Corp. Seattle, Washington). This is illustrated in the pilot study (Konchak et al. 1987). The surface EMG electrodes were applied over the right and left temporalis and masseter muscles in strict accordance with Jankelson's methodology (1981).

EMG recordings were made prior to TENS stimulation, and the adaptive freeway space was measured from the prepulsed vertical dimension of the occlusion. Subjects were then given a minimum of 40 minutes of TENS immediately prior to recording true freeway space values.

It has previously been established by Thomas (1986) that the masticatory muscles are reliably relaxed at EMG values of 14 UV or less, so this EMG criterion was used to group the patients into relaxed and non-relaxed categories.

RESULTS

Four categories of patient groups were established on the basis of the above criteria:

Type A - relaxed before and after muscle stimulation

Type B - not relaxed before or after muscle stimulation

Type C - not relaxed before, but relaxed after muscle stimulation

Type D - relaxed before, but not after muscle stimulation

The average freeway space value before the muscle stimulation was 2.6mm, and after the stimulation it was 3.4mm. These values in the pilot study were 1.8mm before and 2.9mm after stimulation. S-N/MP averaged 33.4 +/- 6.9o, and the percent nasal was 45.4 +/- 2.0%.

It is interesting to note that Group D, albeit a very small sample size, was the only group where the average FWS decreased after TENS. This was the group that demonstrated increased muscle activity after muscle stimulation.

Jankelson (1981) has previously discussed the fact that freeway space has not only a vertical but also an anteroposterior component. He found the A/V (anterior to vertical) ratio to be 1:2, whereby a closing trajectory of the mandible results in a 1mm anterior movement in conjunction with 2mm of vertical movement. This study found an A/V ratio of 1:1.8($r=.72$), confirming Jankelson's findings.

SUMMARY AND CONCLUSIONS

- Four categories of relaxation of the masticatory musculature were determined in patients before and after TENS.
- 58% more patients achieved masticatory muscle relaxation after TENS (50% before, 79% after).
- The average freeway space measurement increased after TENS. Differences for individual patients in their pre- and post-stimulation freeway space values, however, could be either positive or negative, as some experienced an increase in masticatory muscle activity following TENS stimulation.

- Clinical and true freeway space values are inversely correlated with the SN/MP angle, but the correlation values are low.
- Angle classifications were not correlated with freeway space.
- S-N/MP angle and percentage nasal height were inversely correlated.
- No correlation was found between percentage nasal height and FWS. Descriptive factors obtained from cephalometric measurements such as percentage nasal height and S-N/MP angle can be useful in diagnosis and treatment planning, but these values must be correlated with the clinical examination,
- Previously accepted and unchallenged concepts of freeway space and vertical dimension such as those postulated by Guichet (1970) and Lindegard (1953) were not borne out by our application of kinesiographic technology.

In applying FWS values as an aide to orthodontic diagnosis and treatment planning, individual patient values are of greater significance than are group averages. In ongoing studies, individual patient's freeway space before and after treatment are being investigated to see whether this parameter is important in influencing the ultimate stability of the occlusion.

Hannam, et al, utilized the Mandibular Kinesiograph and EMG to evaluate muscle activity and mandibular movement. The study concluded that alteration of the occlusion influences muscle contraction patterns and jaw movement patterns during mastication.

Hannam, A.G., et al. The relationship between dental occlusion, muscle activity and associated jaw movements in man. Archives Oral Biol. 22:25, 1977.

SUMMARY

Experiments were carried out on adult subjects before and after occlusal adjustment, and during atypical mastication, to study the relationship between occlusion of the teeth, muscle activity and associated jaw movements. A computer-based system was used to record and analyze the electromyographic activity in the right and left anterior temporal, posterior temporal and masseter muscles, as well as the displacement, in 3 planes, of an incisor point on the mandible. Clinical examination of the occlusion was performed by means of a standard procedure, which permitted numerical values to be assigned to variables commonly observed in clinical practice. Unilateral gum-chewing tasks were carried out by each subject. Five subjects were tested both before and two weeks after occlusal adjustment. Two subjects acted as controls. The series also included one subject with a history of bruxism and another who undertook specific chewing tasks. The results indicated a tendency for occlusal adjustment to be associated with an increase in the lateral excursions of the mandible during jaw closure and, in some cases, with a closer approximation of peak muscle activity to the intercuspal position of the teeth. Specific occlusal features showed no clear association with either muscle activity or jaw displacement, although all subjects developed maximum muscle effort very close to, or at, the intercuspal position. Jaw-closing speed during natural chewing appeared to decrease abruptly before maximum bolus resistance was met by the teeth suggesting the existence of a neuromuscular control mechanism which operates before closing forces become very large.

INTRODUCTION

There is little information available concerning the relationship between muscle activity and jaw movement during normal function in man, despite the significant amount of data which has been accumulated in separate studies of these two parameters (Hannam, Scott and De Cou, 1976). As a result, though efforts have been made to relate the state of the dental occlusion to the electromyographic activity in the muscles of mastication, or to patterns of jaw movement, (Ahlgren, 1967; Schaerer, Stallard and Zander, 1967; De Boever, 1969; Troelstrup and Moller, 1970; Gibbs et al., 1971; Griffin and Munro, 1971; Gillings, Graham and Duckmanton, 1973), the lack of quantitation of all three variables at the same time has severely hampered understanding of their precise association during function. The need for a clearer definition of this relationship is confirmed by present approaches to the clinical management of mandibular dysfunction syndromes, when alterations are frequently made to the occlusion to alleviate signs and symptoms of dysfunction in the muscles of mastication, or mandibular joints. While such treatment is often effective, the physiological changes which ensue are poorly understood.

We have described a computer-based system (Hannam et al., 1976) which allows the simultaneous measurement of muscle activity and jaw movement during function. Our present aim was to use this facility to investigate the relationship between selected parameters of dental occlusion, muscle function and jaw movement during unilateral chewing and voluntary clenching tasks in man.

METHODS

Only a few parameters were selected for study from the variety which were recorded. Given the relatively small sample size available at the beginning of an ongoing project, it seemed reasonable to search for associations between those parameters which might have the best correlates. Emphasis was placed upon lateral jaw movement in the last few mm of closing, peak muscle activity, the relationship in time of both these parameters to the position of maximum intercuspation of the teeth, and a few selected parameters of occlusion viz, non-working side interferences, interferences in maximum intercuspation, slides from maximum intercuspation, and working side contacts.

The data were obtained from nine adult subjects with natural dentitions. Five of the subjects underwent occlusal adjustment by selective grinding of the teeth between recording sessions, 2 acted as controls for this group, one had a history of bruxism, and one was instructed to perform a forced, vigorous chewing task.

The methods used to assess the electromyographic activity of right and left anterior temporal, posterior temporal and masseter muscles and the movement, in three dimensions, of an incisor point on the mandible, are reported elsewhere (Hannam et al., 1976). Briefly, surface electromyography was used to derive signals from the 6 elevator muscles, and a displacement transducer, consisting of an assembly of magnetometers attached to a headframe, was used to sense the movement of a small magnet cemented to the lower anterior teeth (Kinesiograph, Myotronics Inc., Seattle,

Wash.). After appropriate conditioning, the 9 signals were sampled by a disc-based computer system (HP 2100, Hewlett-Packard, Canada, Ltd.), while the subjects carried out a series of chewing and clenching sequences. Computer samples were taken during the closing phase of 30 right-sided, gum-chewing sequences, 30 similar left chewing sequences and 30 open-close-clench sequences into maximum intercuspation. In addition, voluntary gliding movements made by the subjects with the teeth in contact were used to define the envelope of motion determined by the teeth themselves.

DISCUSSION

Alteration of the occlusion by selective grinding clearly appears to influence muscle contraction patterns and related jaw movements in mastication, at least over a 2-week period. The changes wrought in dentition by adjustment tended to standardize the occlusion of each subject. Very broadly, this end-point includes a stable platform in the intercuspal position which is coincident with the most retruded contact position and a freedom from non-working side contacts and posterior contacts in functional lateral and protrusive movements. It is therefore probable that, in the process of reaching these objectives, the removal of premature tooth contacts in centric relation and the removal of non-working side and posterior protrusive guidance, or both, resulted in the changes seen, viz, a tendency to increase the lateral movement of the mandible during closing, and to cause peak muscle contraction to occur more nearly at the position of maximum intercuspation.

It is conceivable that in the adjustment procedure, working-side contacts were reshaped in such a way as to allow a flatter approach during jaw closure. This factor was not quantitated, as only the number, position and severity of contacts were recorded. However, it is not likely to have been a major influence on movement patterns, for in the majority of cases the canine teeth made contact in lateral movement before adjustment, and still retained functional contact, albeit more strongly, following adjustment.

On the other hand, it is difficult to differentiate between the effect of removing premature contact in centric relation, and the effect of removing non-working side contacts upon lateral jaw movements, as both procedures were carried out at the same time. It would seem reasonable to attribute increases in lateral excursions to the removal of the non-working side interferences. Ahlgren (1967), for example, has demonstrated that a high percentage of subjects with interferences in centric relation, and a slightly greater percentage with interferences on the non-working side, display chopping masticatory strokes. Although it is not clear from his work, how many times the two kinds of interference occurred together, the larger sample of subjects who demonstrated non-working side contacts implies that this feature alone may have a strong influence upon the degree of lateral jaw movement. However, the relationship between non-working side tooth contacts and jaw movement patterns is far from clear from our study. Even with some fairly large increases in lateral displacement in the small sample, no simple relationship could be demonstrated. Even less explicable is the occurrence in some instances, of reduced lateral movement following occlusal adjustment. Whether it will be possible to demonstrate and explain an association between jaw movement patterns, which are subject to a variety of influences other than the teeth, and tooth contact patterns, when they are recorded by patient-guided or border movement approximations of the opposing dental arches, must await further analysis of larger samples.

Our study shows that there was a tendency, following equilibration, for the peak muscle activity to occur closer both in time and space, to the intercuspal position. The significance of this event is not clear unless other features of the muscle contraction are taken into account. For example, in one subject, despite an insignificant change in a vertical closing pattern after adjustment, the mean peak activity in the right and left posterior temporal muscle actually moved significantly away from the intercuspal position, probably being associated with the significantly slower terminal closing time which occurred following adjustment, as both differences were about 30 msec. However, the total duration of contraction of the right posterior temporal muscle was actually more than doubled, and that of the left posterior temporal muscle more than halved. This example shows that, while peak activity undeniably indicates where maximum effort is reached by the muscles, it does not necessarily indicate how the overall effort is distributed following occlusal adjustment, and as such should not be the only index used in the estimation of force distribution in the closing cycle; for example in the subject with bruxism the muscles were still electrically active at over 50 per cent of their peak response level well in to the intercuspal position, even though peak activity occurred before the position was attained.

The delay between the electrical activity in the elevator muscles and the development of tension is approximately 70-80msec (Ahlgren, 1967; Ahlgren and Owall, 1970; Hannam, Ikster and Scott, 1975) so that peak tension will occur in most instances very close to the intercuspal position, a phenomenon noted by others (Ahlgren, 1967; Ahlgren and Owall, 1970; Gibbs et al. 1971; Gibbs, 1975). It can therefore be reasoned that, if the masticatory system is designed so that high masticatory forces are best withstood in the intercuspal position, the tendency for peak electromyographic activity to move closer to this position following occlusal adjustment may be considered beneficial.

The jaw displacement data recorded from the subject carrying out voluntary chewing tasks are consistent with those reported in a study involving chewing and clenching tasks (Hannam, Inkster, De Cou and Scott, 1976) in which mean jaw closing speeds during normal mastication of gum by a group of subjects was 110 mm/sec., contrasting with a speed of closing during voluntary clenching tasks of 183 mm/sec.. Our present study suggests that the resultant closing speed decreases rapidly early in the closing cycle during gum chewing, that at this point the incisors may be quite widely separated, and that significant increases in muscle activity occur much later in the cycle. These results imply that bolus contact, rather than bolus resistance, may be a key influence upon the pattern of normal mastication. The ability of the subject to override this influence voluntarily is shown by the effect of forced mastication, where the usual pattern of mastication is markedly altered, and emphasizes the plasticity of the masticatory system in function.

Belser and Hannam used the Mandibular Kinesiograph and EMG to analyze masticatory EMG activity and mandibular movement during function.

Belser, U.C. and Hannam, A.G., The contribution of the deep fibers of the masseter muscle to selected tooth-clenching and chewing tasks. J. of Prosthet Dent. Nov. 1986, Vol 56, No. 5, pp 629-635.

MATERIALS AND METHODS

PRELIMINARY STUDY

The EMG signals were amplified and filtered by means of optically isolated amplifiers and led to the A to D converter of a disk-based computer (HP 1000 Series E and peripherals, Hewlett-Packard, Canada Ltd.). Sampling of each channel took place every msec, and continuous 5 msec running averages of each rectified muscle response were stored for further analysis. This system has been described in more detail. (Hannam, Scott and De Cou, 1977, Hannam, De Cou, Scott and Wood, 1977, Hannam and Wood 1981)

Simultaneous displacement of a lower incisor point was recorded in three planes by means of an electronic transducer especially designed for the purpose (Mandibular Kinesiograph, Myotronics, Research Inc., Seattle, Wash.). Each of the three analogue displacement signals was sampled every msec along with the muscle data and stored as a series of 5 msec running averages. A more detailed description of the kinesiographic measurement method can be found elsewhere. (Jankelson, Swain, Crane and Radke, 1975, Hannam, De Cou, Scott and Wood, 1980)

Each subject carried out 10 maximum clenching efforts for one second in the intercuspal and incisal edge-to-edge occlusal positions. All clenching efforts were directed vertically to the occlusal plane. The computer generated periodic visual signals to cue the onset and duration of each clenching act. Following the sampling and storage of the associated signals, muscle activity over the central 400 msec of each response was averaged. These averages were used to calculate a task average representing the mean EMG response for the series of 10 efforts.

SUMMARY AND CONCLUSIONS

Anatomically, the human masseter muscle consists of at least two portions (pars superficialis, pars profunda) with distinctly different fiber directions. The purpose of this study was to describe functional behavior in the deep fibers of the masseter muscle and to define any differences in its behavior from that of the superficial fibers. In 20 subjects, EMG activity of the superficial and the deep portions of the masseter muscle was recorded during specific parafunctional (intercuspal and eccentric tooth clenching) and functional (unilateral chewing) tests. Superficial and deep activity was measured with bipolar surface electrodes and intramuscular fine-wire electrodes. Simultaneously, displacement of a lower incisor point was recorded in three dimensions. The data were collected and stored for analysis by a disk-based computer system.

The results indicated that changes in the direction of effort, in mandibular position, and in the side used for chewing all influenced activity in both parts of the muscle to different extents. The most distinct separation of activity occurred when intercuspal clenching was directed retrusively; the deep fibers of the masseter muscle response reduced to 47.5% of its maximum value while that of the superficial fibers of the masseter muscle fell to 5.5%. During chewing, activity in the deep fibers of masseter muscle was distributed evenly bilaterally, whereas that in the superficial fibers of the masseter muscle was biased significantly toward the chewing side.

Differentiation of activity within the masseter muscle may be relevant to the distribution of regional tenderness in the muscle when it is involved in parafunctional activity. The results suggest that retrusively directed occlusal grinding or clenching behavior, often manifested by wear facets on the molar and premolar teeth can be expected to be associated with strong activity in the deep fibers of the masseter muscle. Tenderness as a consequence of its excessive contraction might therefore be predicted in the preauricular region anterior to the temporomandibular joint, a region that can be palpated easily during clinical examination.

Neilsen, et al, studied the ability of 17 normal and 33 dysfunction patients to achieve predetermined jaw positions during opening. The data suggested that neuromuscular control is altered in patients with craniomandibular muscle pain, but not by degenerative TMJ changes.

Nielsen, L.L., Ogro, J., McNeil, C., Danzig, W.N., Goldman, S.M., and Miller, A.J. Alteration in proprioceptive reflex control in subjects with craniomandibular disorders. J. of Craniomandibular Disorders: Facial and Oral Pain. Vol 1, No. 3, pp 170-178, 1987.

Proprioceptive reflex control of mandibular positioning was impaired in subjects with mandibular muscle pain. Tracking of mandibular movement, by observing the movement of a reference point placed at the lower incisors, showed that control subjects and patients with muscle pain projected beyond (i.e., overshoot) a predetermined target position before reaching the final point. Patients with muscle pain demonstrated significantly less precision in achieving a predetermined mandibular position and a greater range in the overshoot.

Mandibular position is precisely controlled in the human and is postulated to rely heavily on proprioceptive feedback from the temporomandibular joints (TMJs) and masticatory muscles. (Thilander 1961, Larsson, et al. 1964, Owall 1978, Ramsjö 1963, Christensen, et al 1975, Carraro, et al. 1970, Storey 1976, 1985.) This proprioceptive input synapses both within the trigeminal sensory nucleus and the primary sensory cortex and affects motor trigeminal neurons via reflex arcs to alter craniomandibular muscle activity. (Dubner, et al. 1978)

The ability to repeatedly attain an arbitrary position of the mandible between posture and maximum opening was first reported by Thilander (1961) and Ramsjö and Thilander. (1963) The variation in attaining a predetermined jaw position in normal subjects was found to be 3.4 mm, as tested with a calibrated wood spatula measuring interincisor position between the lowest and highest values. Further work by Thilander (1961) and Christensen and Troest (1975) has shown that anesthetizing the TMJ capsule with its ligaments resulted in an increase in the range in precision of determining mandibular position Christensen and Troest (1975) have shown that applying a local anesthetic to the lateral pterygoid muscle also significantly increased the range of the mandibular kinesthetic test. This study suggests that either sensory feedback from the lateral pterygoid muscle or impairment of the reflex arc controlling lateral pterygoid activity and condylar position modifies the process by which a subject knows and reproduces a mandibular position

METHODS AND MATERIALS

JAW TRACKING

Each subject was asked to sit upright in a chair. A magnet was placed below the mandibular medial incisor using a moisture-activated adhesive (Stomahesive, Squibb). A headgear from the Kinesiograph with magnetic field sensors, modified according to Hannam et al., (1980) was placed on the patient's head. (Lewin 1974) Movement of the mandible was tracked in the frontal plane and plotted on an X-Y plotter (Watanabe) at a magnification of 2 x.

The vertical measurements in the frontal plane were corrected for the nonlinearity of the Kinesiograph by means of calibration graphs.

STATISTICAL ANALYSIS

The extent of the maximum opening in the frontal plane was measured first; then the distance from the intercuspal position to each target position; and finally the length of the overshoot beyond the target position. Measurements were completed using a calibrated graph which permitted correction of the measurements for the lack of linearity of the Kinesiograph.

RESULTS

CONTROL SUBJECTS

The control subjects demonstrated a significant difference in the mean range of jaw opening between the <50% opening and the >50% opening. The range was greater at the >50% jaw opening ($P < .025$) than at the <50% mandibular opening. The overshoots at both the <50 and the >50% jaw openings were similar and not statistically different.

At <50% Jaw Opening. The range and standard deviations were compared between the four groups of patients with muscle pain and the normal subjects. None of the patients with muscle pain and the subjects with pain in both head and neck muscles, including the subgroup with joint degeneration, demonstrated a greater range or standard deviation than the control subjects. However, the subgroup with pain in the masticatory muscles only (and no pain in cervical or neck muscles) demonstrated a significantly greater range ($P < 0.05$) and less precision than the normal subjects.

At >50% Jaw Opening. In contrast to the results at the small mandibular opening, patients with muscle pain demonstrated a significant increase in the range of reaching the same mandibular position when tested at >50% of their maximum opening. Patients in the broadest category of muscle pain, those subjects with pain in masticatory and cervical muscles, and those with such pain and joint degeneration, demonstrated significantly greater ranges than normal subjects. This finding was supported by the analysis of the standard deviation which showed that the patients with pain in both masticatory and cervical muscles, and subjects with joint degeneration, exhibited larger standard deviations. The only group of patients that did not exhibit a significantly different range were those with pain only in masticatory muscles. These subjects exhibited greater ranges only at the smaller jaw opening of <50%.

Overshoot at <50% Jaw Opening. The overshoot is the linear distance by which a subject exceeds the predetermined opening. In the control subjects, the range and standard deviation of the overshoot was similar between the small mandibular opening at <50% and the larger opening at >50% in the midrange of total excursion. Comparing the four groups of patients with the normal subjects at the small jaw opening of <50% showed that the range did not vary between the groups ($P < 0.05$).

Overshoot at >50% Jaw Opening. The patients with muscle pain and with pain only in the masticatory muscles, or pain in both head and neck muscles with or without joint degeneration, demonstrated significant increases in both their ranges and standard deviations of their overshoots at the >50% opening as compared to the control subjects. All patients, regardless of the location of the pain or whether the joint demonstrated degenerative changes, showed significant increase in the degree of overshoot as defined by both the range and standard deviation.

DISCUSSION

Our study, using jaw tracking with the Kinesiograph, shows that subjects will exceed the pre-determined target position and then return to this position. This overshoot was similar for the two mandibular positions tested in normal subjects. The overshoot may represent a normal delay in the comparison of the sensory feedback to the descending motor signal. This sensory feedback indicates the actual length of the muscle spindles in the jaw elevator muscles and includes input from the joint receptors that continuously discharge during increasing movement of the mandible.

SUMMARY

Seventeen normal subjects and 33 subjects with masticatory muscle pain were studied for their precision in actively attaining predetermined mandibular positions during jaw opening. The subjects were seated upright in a chair without head support. With their eyes closed, they were then requested to open their mouth to one of two arbitrary mandibular positions selected by the investigator. The subjects maintained this position for 20 seconds and then closed and repeated the same opening in ten trials of opening and closing.

The reproducibility of two different jaw openings; one at approximately <50% of the maximum mandibular opening; and one at >50% of the maximum opening was then tested. The mean, standard deviation, and range for each of the series of ten trials were determined. The movement of the mandible during this test was tracked with the Jankelson's Kinesiograph, in which a magnetic sensing system recorded the movements of a small magnet placed at the mandibular incisors.

The control subjects demonstrated a significant increase in the range of opening in the ten trials ($P < .025$) and the >50% jaw opening level as compared to the <50% opening. The jaw tracking provided precise recording of the movement pattern in the frontal plane and showed that subjects usually opened wider than their predetermined target position and then closed to the determined position. The range of variation of the "overshoot" did not differ significantly between the <50% and >50% jaw opening trials indicating normal subjects overshoot their target position to the same degree for both mandibular openings.

Subjects with muscle pain were divided into three subdivisions: (1) those with pain in both masticatory and cervical muscles ($N = 33$); (2) pain in mandibular muscles only ($N = 5$); and (3) pain in mandibular and cervical muscles with joint degeneration ($N = 10$). In the mandibular position tested at the small opening (<50%), only the group with masticatory muscle pain demonstrated a significant difference in comparison to the control group ($N = 17$). At the larger opening (>50%), all subjects with muscle pain, the subjects with pain in mandibular and cervical muscles, and the subjects with pain in these muscles and joint degeneration all demonstrated a significantly greater range and less precision. Subjects with pain only in the masticatory muscles did not demonstrate significant differences at the larger opening possible due to the small sample.

At the small opening, i.e., <50% of the maximum, the subjects with muscle pain did not demonstrate any difference in the range and standard deviation of the overshoot. In contrast, both the range and standard deviation for the overshoot were significantly larger in all patients with muscle pain and their subcategories as compared to normal subjects when tested at the >50% opening.

These data suggest that the neuromuscular control with which an individual determines mandibular position is altered in subjects with craniomandibular muscle pain, but not further influenced by degenerative joint changes within the temporomandibular joint (TMJ).

Neill and Howell used the Mandibular Kinesiograph to analyze mandibular movement in 97 young adult patients. Data conclusions were preliminary and further investigation is being conducted.

Neill, D.J. and Howell, P.G.T. Computerized kinesiography in the study of mastication in dentate subjects. J. of Prosthet Dent. May 1986, Vol 55, No. 5, pp 629-638.

In an attempt to achieve a better understanding of the chewing mechanism, research has been directed at identifying the nature of jaw movement together with observations of the associated neuromuscular control.

Beck and Morrison (Beck and Morrison 1962) reported the development of the mandibular replicator with extraoral frameworks that attached to the teeth of both jaws. The replicator carried sensors located in three widely separated points and monitored the spacial movement of the mandible. Although a number of researchers have used this or a similar apparatus to reveal valuable information concerning border movements and condylar shift, the nature of the equipment so intrudes on the subject's level of consciousness as to render it unsuitable to record the movements that occur in normal function.

Although tracing the movement of a single point on the mandible has limitations on the interpretation of jaw movement, it has merit of requiring less obtrusive markers. The earliest recorded studies of single-point movement are attributed to Luce (Luce 1889) who in 1889 used still photography to record the path of movement of a light source attached externally to the mandible. Hildebrand, (Hildebrand 1931) reporting his cineradiographic and cineradiographic experiments on masticatory movement, included a review of the literature in 1931. Ahlgren (Ahlgren 1966) and others have since used a similar technique necessitating immobilization of the subject's head to ensure that the recorded movements were those of the mandible alone.

The Mandibular Kinesiograph (Myotronics Research Inc., Seattle, Wash.) (Jankelson, et al. 1975) and the Sirognathograph (Siemens AG, Bereich Medizinische Technik, Kaufmannshelietung, Germany) (Lewin, et al. 1974) both enabled jaw movement to be monitored without the head being restricted and without the need for any connection between the intraoral marker and the transducing element. Both depended on a change in magnetic flux occurring when a small bar magnet attached to the labial aspect of the mandibular incisor teeth moved relative to sensors mounted on the framework attached to the subject's head.

The relative merits of the two instruments have been investigated and reported. (Neill 1984) The Kinesiograph proved to be the more versatile of the two instruments and has been used in our studies. It was capable of being linked by way of an analogue to digital converter to a micro-computer for the storage, retrieval, and analysis of data. Calibration of the equipment was done and a short computer program written in Basic corrected errors and ensured a linear response.

RESULTS

PATTERN OF JAW MOVEMENT: SAGITTAL PLANE

Whenever tooth contact occurred it appeared to be in centric occlusion. Although some subjects consistently showed the opening stroke to be in front of the closing stroke, in others as many as 50% of the closing strokes occurred in a forward position. The angulation of the sagittal pathway was normally directed upward and backward, reflecting the rotational element in mandibular opening, but this tended to be more vertical with those subjects having a deep incisor overlap.

DIMENSIONS OF THE CHEWING CYCLE

The mean lateral range of movement varied from 4.9 mm to 6.7 mm. Men had a wider lateral range than women. Irrespective of sex, the range of lateral movement was generally less for subjects with a Class II, division 2 dentition.

The mean maximum vertical opening varied from 14.5 mm to 18.7 mm and again, irrespective of the test food, men had a greater opening than women. The widest separation and lateral deviation for all groups and both sexes was found in the chewing of cookies.

CYCLE TIME

The mean cycle times varied from 0.73 secs to 0.86 sees. Despite the smaller range of jaw movement in women, the cycle time was longer for all of the test foods. The cycle times were greater for beef and chewing gum than for other foods, which were not significantly different.

TOOTH CONTACT SLIDE

By amplifying the portion of the chewing cycle adjacent to tooth contact and tooth guidance in lateral excursion, it has been possible to measure the length of the tooth contact glide into and out of the intercuspal position for a group of 33 subjects. This ranged from 0 to 4.5 mm and the mean values for each subject were determined.

The combined values of closing and opening slides pooled for subjects in the four different orthodontic groups and for the five different foods are shown in Table VIII. They range between 1.38 mm and 2.8 mm and in each group the longest contact glide occurred with peanuts.

CONCLUSIONS

The chewing activities of 97 young adult subjects were studied by analyzing the movement of a single point on the mandible in the frontal and sagittal planes.

Differences were found between men and women with respect to cycle time, velocity of movement, dimensions of the chewing envelope, and the duration of the pause in the intercuspal position. The nature of the test food also had a bearing on the values of each of these parameters.

The subjects were grouped according to incisor relationship which appeared to have some bearing on the extent of the tooth contact slide and the path of movement in the sagittal plane. However, the data on which these observations were made were too small to draw valid conclusions and this aspect of the study will be expanded in a further series of investigations.

Hannam, et al, used the Mandibular Kinesiograph and EMG to quantitate and compare muscle EMG activity and mandibular movement. After evaluation of the advantages and disadvantages of these modalities, the authors conclude that significant information about muscle function and jaw movement during mastication and the effects of conventional occlusal treatments can be obtained.

Hannam, A.G., Scott, J.D., and De Cou, R.E. A computer-based system for the simultaneous measurement of muscle activity and jaw movement during mastication in man. Archs Oral Biol Vol 22, pp 17-23, Pergamon Press, 1977.

SUMMARY

A computer based system was developed in order to analyze the activity of 6 jaw closing muscles and the associated displacement in 3 dimensions, of an incisor point on the mandible, during gum-chewing and clenching sequences. Signals were derived by surface electromyography from the right and left anterior temporal, posterior temporal and masseter muscles, and by means of a set of magnetometers which sensed the movement of a small magnet cemented to the lower incisor teeth. Sampling of those signals by the computer was locked in phase to the chewing cycle, and the digitized signals were conditioned and analyzed by software to permit quantitation of a wide variety of parameters. The system proved non-invasive and allowed repeated measurements to be made on different occasions. It is suggested that the technique should be useful in the study of masticatory mechanisms, and in assessing the effects of clinical alterations to the occlusion

MATERIALS AND METHODS

JAW DISPLACEMENT

Jaw displacement in 3 planes was recorded continuously with a non-invasive electronic transducer (Kinesiograph, Myotronics, Inc. Seattle, Washington) which allowed the movement of a magnet rigidly secured to the mandible to be monitored by a set of magnetometers carried in a light headframe (Jankelson et al, 1975). A small magnet was fixed by means of acrylic cement to the labial surface of the lower anterior teeth and gum, 1 mm below the edge of the upper incisors, the teeth being clenched in maximum intercuspation. The orientation of the magnet was carefully controlled with a modified dental facebow (Whipmix Corp., Louisville, Kentucky) cemented in the midsagittal plane, parallel to the Frankfort plane which was also used as a reference for placing the sensors. These were carried on the headframe of aluminum bars attached to a spectacle frame by an elastic head strap. Precise alignment of the sensors relative to the magnet was accomplished by a set of calibrated blocks.

To create a wide, linear working range for the system, we did not follow the manufacturer's instructions exactly and the apparatus was bench-calibrated with the top face of the vertical movement sensor 6.9 cm from the top of the magnet and the inside surface of the anterior-posterior movement sensor 4.3 cm from the front face of the magnet. With the gain of the instrument set so that a 4 cm vertical excursion produced -5 V, a +1 cm lateral excursion +1 V, and a ÷ 1 cm anterior-posterior excursion +1 V, the magnet was moved systematically in a three-dimensional lattice with a wooden rod attached to calibrated micromanipulators. Calibration curves were then constructed for each of the 3 planes of movement enabling a linearizing program to be written for the computer so that, after sampling, the displacement data would be automatically corrected. It was possible thus to measure to an accuracy of +0.25 mm, anywhere within the cube 2 cm wide, by 2 cm deep, by 4 cm in height.

To estimate the accuracy which could be expected in day to day placement of the entire apparatus on a given subject, an acrylic bit block was constructed for one subject so that the mandible could be reproducibly placed in an open, lateral and posterior position. On each of 3 separate days, the apparatus was set up on the subject, and the bite block inserted and removed 5 times, readings being taken each time. The mean jaw opening was 19.3 mm. SD + 0.4, lateral displacement 3.2 mm S.D. + 0.8, and antero-posterior displacement 3.5 mm S.D. +1.3 (n=15), the measurements being taken from the intercuspal position relative to the midline sagittal plane, Frankfort horizontal plane and a frontal plane perpendicular to the Frankfort plane. Although it was estimated that the day to day error in recording lateral measurements would be less than 0.4 mm in the last cm of jaw closing, the error in antero-posterior measurements was considered large enough to warrant additional precautions during subsequent use of the system. Therefore, in all later recordings involving repeated measurements of subjects, a bite block at an arbitrary incisal separation of about 15 mm was constructed for each subject and used to check the alignment of the system during every experimental run

RESULTS

Figures 4 and 5 demonstrate mean electromyographic and displacement data collected during sequences of right-sided, unilateral chewing carried out by the same subject on two different occasions, separated by two weeks. Both the patterns of muscle contraction and the patterns of jaw movement determined for this subject are consistent with those reported by Moller (1966) and Ahlgren (1966, 1967a).

The mean contraction patterns appear to be very consistent, and at the same time, demonstrate a feature common to many subject with Class III malocclusions, viz, a tendency to show reduced functional activity in the masseter muscles relative to that in the temporal musculature. The subject in fact had a marked Class III tendency, and confirmation of the apparent decreased functional activity in the masseter muscles was obtained by demonstrating, on both occasions, a 5-fold increase in the mean peak activity of the four temporal muscles relative to the two masseter muscles during the clenching task in the intercuspal position.

Comparison of the two displacement records shows that while the closing strokes were essentially the same in term of lateral deviation of the mandible, the subject opened less widely and more posteriorly during his second trial. This reduced excursive movement was associated with a more rapid chewing cycle, as the time take to reach maximum intercuspatation (CO) from maximum jaw opening fell from 498 msec S.D. \div 50 in the first trial, to 419 msec S.D. + 35, in the second. However, the ratios of time taken from the 5 mm open position to the time from maximum jaw opening to maximum intercuspatation were 0.45 and 0.47 respectively for the two trials, indicating that these two phases of the closing cycle were proportionally the same, despite differences in the overall cycle times. By the time the incisor point was within 2 mm of the intercuspal position, a time when most muscles were very active, the two displacement patterns were essentially identical.

DISCUSSION

The flexibility of the system described permits a wide variety of parameters to be quantitated and compared. It has the advantages of simplicity and comfort so far as the subject is concerned and provides a versatile and readily adaptable system to meet the operator's demands. For instance, by increasing the storage facility of the computer, a detailed analysis of jaw opening can be included. In addition, other electrode systems can be used, and other muscles sampled if required. Finally, a variety of methods can be applied to smooth, reduce and quantitate the data.

Two disadvantages of the system are the limitations placed by recording a single point of movement on the mandible, and the use of surface electromyography to assess muscle responses. The former does not permit a reliable assessment to be made of condylar movements during function, and the latter limits the muscles which can be sampled during function. As the price which must be paid to remove these drawbacks is to increase the invasiveness of a system which already must influence normal function to some degree, there would seem to be room for compromise. We feel that even in its present form, the system can provide significant information about muscle function and jaw movement during mastication, and at the same time provide a yardstick for the comparison of the effects of conventional occlusal treatments. (Hannam, Scott, De Cou and Wood, 1976)

SECONDARY REFERENCES

[Jaw Tracking Studies cited within the articles reviewed in this publication]

- Ahlgren, J. (1966) Mechanism of mastication. *Acta Odontol Scand.* 24, (Suppl 44):9.
- Ahlgren, J. (1967) Pattern of chewing and malocclusion of the teeth. *Acta Odont. Scand.* 25, 3-14.
- Ahlgren, J., and Owall, B. (1970) Muscular activity and chewing force, a polygraphic study of human mandibular movements. *Arch. Oral Biol.* 15, 271-280.
- Anthony, C.P. and Koithoff, N.C. (1975) *Textbook of Anatomy and Physiology.* The C. V. Mosby Co. pp 108-120, St. Louis.
- Atkinson, H.F. and Shepherd, R.W. (1961) Temporomandibular joint disturbances and associated masticatory patterns. *Austral. D. J.* 6:4, 219- 222.
- Atwood, D.A. (1956) A cephalometric study of the clinical rest position of the mandible. Part I: The variability of the clinical rest position following the removal of occlusal contacts. *J. Prosthet. Dent.* 6:504-519.
- Bando, E., Fukushima, S., Kawabata, H., and Kohno, S. (1972) Continuous observations of mandibular positions by telemetry. *J. Proth. Dent* 28, 485- 490.
- Bates, J.F., Stafford, G.D. and Harrison, A. (1975) Masticatory function - A review of the literature (I) The form of the masticatory cycle. *J. Oral Rehabil.* 2:281.
- Beck, H.O., Morrison, W.E. (1962) Method of reproduction of movements of the mandible. Research report. *J. Prosthet. Dent.* 12:873.
- Burke, P.H. (1971) Stereophotogrammetric measurement of normal facial asymmetry in children. *Hum. Biol.* 43:53 6.
- Carlsoo, S. (1956) An electromyographic study of the activity of certain suprahyoid muscles (mainly the anterior belly of digastric muscle) and the reciprocal innervation of the elevator and depressor musculature of the mandible. *Acta Anat.* 26:81-93.
- Carlsson, G.E. (1985) Long-term effects of treatment of craniomandibular disorders. *J. Craniomand. Pract.* 3:337-342.
- Carraro, J.J., Albano, E., Caffesse, R., et al. (1970) La perception postural mandibularen el sindrome temporomandibular. *Rev. Assoc. Ordont. Argent.* 58:22- 25.
- Christensen, L.V., Troest, T. (1975) Clinical kinesthetic experiments on the lateral pterygoid muscle and temporomandibular joint in man. *Scand. J. Dent. Res.* 83:238-244.
- Dahlstrom, L., and Haraldson, T. (1985) Bite plates and stabilization splints in mandibular dysfunction. A clinical and electromyographic comparison. *Acta Odontol. Scand.* 43:109-114.
- Dahlstrom, L., Carlsson, G.E., and Carlsson, S.G. (1982) Comparison of effects of electromyographic biofeedback and occlusal splint therapy in mandibular dysfunction. *Scand. J. Dent. Res.* 90:151-156.
- De Boever, J. (1969) Experimental occlusal balancing - contact interference and muscle activity. *Parodontologie.* 23, 59-69.
- Dixon, H. H., O'Hara, M., and Peterson, R.D. (1967) Fatigue contracture of skeletal muscle. *NW Med.* 66:813.
- Dixon, W.J., and Massey, F.J. (1969) *Introduction to Statistical Analysis.* McGraw-Hill Book Co., New York. ed.3, p.142.
- Dubner, R., Sessle, B.J., and Storey, A.T. (1978) *The Neural Basis of Oral and Facial Function.* New York, Plenum Press.
- Fujii, H. (1977) Evoked EMG of masseter and temporal muscles in man. *J. Oral. Rehabil.* 4(3):291-303.
- Ganong, W.F. (1985) *Review of Medical Physiology.* Lange Medical Publishers, 12th Ed., p 51.

- Gibbs, C.H., Messerman, T., and Reswick, J.B. (1966) The Case Gnathic Replicator for the Investigation of Mandibular Movements. Engineering Design Report, EDC-4-66-14. Cleveland: Case Western Reserve University.
- Gibbs, C.H., Messerman, I., and Reswick, J.B. (1969) Functional Movements of the Mandible. Engineering Design Center Report, EDC-4-69-24. Cleveland: Case Western Reserve University.
- Gibbs, C.H., Messerman, T., Reswick, J.B., and Derda, H.J. (1971) Functional movements of the mandible. *J. Prosthet. Dent.* 26(6):604-620.
- Gibbs, C.H. (1975) Electromyographic activity during the motionless period in chewing. *J. Prosth. Dent.* 34, 35-40.
- Gibbs, C.H., and Lundeen, H. (1982) Jaw movements and forces during chewing and swallowing and their clinical significance. In *Advances in Occlusion*. eds. C. H. Gibbs and H. Lundeen. Littleton, Mass.: John Wright PSC, Inc.
- Gillings, B.R.D. (1967) Photoelectric mandibulography, a technique for studying jaw movements. *J. Prosth. Dent.* 17(2):109-121.
- Gillings, B.R.D., Graham, C.H., and Duckmanton, N.A. (1973) Jaw movements in young adult men during chewing. *J. Prosthet. Dent.* 29(6):616 -627.
- Godaux, E., and Desmedt, J.E. (1975) Human masseter muscle: H - and tendon reflex. Their paradoxical potentiation by muscle vibration. *Arch. Neurol.* 32:229-238.
- Goodson, J.M. and Johansen, E. (1975) Analysis of human mandibular movement. In Myers, H.M., editor: *Monographs in Oral Science*. Vol. 5, New York, S. Karger.
- Graf, H. (1982) Jaw movement analysis related to occlusion. *J. Dent. Res.* 61:176.
- Griffin, C.J., and Sharpe, C.J. (1962) The distribution of elastic tissue in the human temporomandibular meniscus especially in respect to 'compression' areas. *Austral. D. J.* 7:1, 72-78.
- Griffin, C.J. (1962) The mesencephalic nucleus of the Vth nerve, its distribution and connections. *Austral. D. J.* 7:4, 304-309.
- Griffin, C.J. and Munro, R.R. (1971) Electromyography of the masseter and anterior temporalis muscles in patients with temporomandibular dysfunction. *Arch. Oral Biol.* 16, 929-949.
- Griffiths, M.J. (1975) Telemetry and the study of vertical jaw relations. *J. Dent.* 3:261.
- Guichet, N. (1977) *The New Occlusion Manual*. Anaheim: The Denar Corp.
- Hannam, A.G., Inkster, W.C., and Scott, J. (1975) Peak electromyographic activity and jaw-closing force in man. *J. Dent. Res.* 54, 694, abstract.
- Hannam, A.G., Scott, J.D., and De Cou, R.E. (1977) A computer-based system for the simultaneous measurement of muscle activity and jaw movement mastication in man. *Arch. Oral Biol.* 22(1):17-23.
- Hannam, A.G., De Cou, R.E., Scott, J.D., & Wood, W.W. (1977) The relationship between dental occlusion, muscle activity and associated jaw movement in man. *Archives of Oral Biology.* 22, 25.
- Hannam, A.G. (1979) Mastication in man. In Bryant, P., Gale, E. and Rugh, J., editors. *Oral Conditions and Dental Treatment*. National Institutes of Health, Washington.
- Hannam, A.G., De Cou, R.E., Scott, J.D., and Wood, W.W. (1980) The kinesiographic measurement of jaw displacement. *J. Prosthet. Dent.* 44:88 -93.
- Hannam, A.G. and Wood, W.W. (1981) Medial pterygoid muscle activity during the closing and compressive phases of human mastication. *Am. J. Phys. Anthropol.* 55:359.
- Hedegard, B., Lundberg, M., and Wictorin, L. (1970) Masticatory function - a Cineradiographic Study. IV. Duration of the Masticatory Cycle. *Acta Odont. Scand.* 28:859-865.

- Hildebrand, G.Y. (1931) Studies in the masticatory movements of the human lower jaw. *Skand Arch Physiol Suppl.* 61:7.
- Hoffman, P. (1918) Uber die Beziehungen der Sehnenreflexe zur Wilikurlichen Bewegungen und Zum Tonus. *Z. Biol.* 68:351-370.
- Homma, S. (1959) On evoked electromyogram in human body. In (*Medicine of Japan*). 5:399-407.
- Hsu, J.C. and Mayer, A.U. (1968) *Modern Control Principles and Applications*. McGraw-Hill, N.Y. Chap. 4.
- Ingervall, B. (1964) Retruded contact position of mandible, a comparison between children and Adults. *Odont. Reby.* 15:130-145.
- Jankelson, B., Swain, C.W., Crane, P.F., and Radke, J.C. (1975) Kinesiographic instrumentation: A new technology. *J. Am. Dent. Assn.* 90, 834-839.
- Jankelson, B. (1980) Measurement accuracy of the mandibular kinesiograph - A computerized study. *J. Prosthet. Dent.* 44:656-666.
- Jankelson, B. (1982) Importance of musculature in orthodontic diagnosis and treatment planning. *Myotronics Research Manual*.
- Jankelson, B., and Radke, J.C. (1978) The myomonitor: Its use and abuse. *Quintessence mt. Dent. Dig.* 9:47-52.
- Jankelson, B. (1969) Electronic control of muscular contraction - A new clinical era in occlusion and prosthodontics. *Sci. Ed. Bull. mt. Coil. Dent.* 2:29.
- Jankelson, B., Swain, C.S., Crane, P.F., Radke, J.C. (1975) Kinesiometric instrumentation: A new technology. *I. Am. Dent. Assoc.* 90:835.
- Jemt, T., Karlsson, S., and Hedegard, B. (1979) Mandibular movements of young adults recorded by intraorally placed light-emitting diodes. *J. Prosthet. Dent.* 42(6):669-673.
- Jemt, T. (1984) Masticatory mandibular movements - Analysis of a recording method and influence of the state of the occlusion. Ph.D. Thesis. University of Goteborg. Swed. *Dent. J. Suppl.* 23.
- Karlsson, S. (1977) Recording of mandibular movements by intraorally placed light emitting diodes. *Acta Ocont. Scand.* 35(2):111 -117.
- King, E.E., Minz, B., and Unna, K.R. (1955) The effect of the brain stem reticular formation on the linguo-mandibular reflex. *J. Corn. Neur.* 102:3, pp. 565-596.
- Konchak, P.A., Lanigan, D.T., Thomas, N.R. and Devon, R.M. (1987) Freeway space measurement by a Mandibular Kinesiograph before and after muscle stimulation. *Angle Orthod.* 57:145-154.
- Kopp, S. (1979) Short-term evaluation of counseling and occlusal adjustment in patients with mandibular dysfunction involving the temporomandibular joint. *J. Oral Rehabil.* 6:101-109.
- Kydd, W.L. (1959) Psychosomatic aspects of temporomandibular joint dysfunction. *J. Am. Dent. Assn.* 59, 31-44.
- Kydd, W.L., and Sander, A. (1961) A study of posterior mandibular movements from intercuspal occlusal position. *J. Dent. Res.* 40:419-425.
- Larsson, L.E., Thilander, B. (1964) Mandibular positioning: The effect of pressure on the joint capsule. *Acta Nuerol. Scand.* 40:131-143.
- Lemmer, J., Lewin, A., and van Rensburg, L.B. (1976) The measurement of jaw movement. Part I. *J. Prosthet. Dent.* 36:211.
- Lewin, A.A. (1974) A method of recording the movement of a point on the jaws. *J. Dent. Assoc. S. Africa* 29:395-397.
- Luce, C.E. (1889) The movements of the lower jaw. *Boston Med. Surg. J.* 121:8.

- Magladery, J.W. (1955) Some observations on spinal reflexes in man. *Arch. Ges. Physiol.* 261:302-321.
- Magnusson, T., and Carlsson, G.E. (1978) Comparison between two groups of patients in respect of headache and mandibular dysfunction. *Swed. Dent. J.* 2:85-92.
- McNamara, J.A., Carlson, D.S., Yellick, G.M., Hendrickson, R.P. (1978) Musculo-skeletal adaptation following orthognathic surgery. In McNamara, J.A., Jr., and Carlson, D.S. *Muscle Adaptation in the Craniofacial Region. Craniofacial growth series.* Center for Human Growth and Development. The University of Michigan, Ann Arbor, MI.
- Mejersjo, C., Carlsson, G.E. (1984) Analysis of factors influencing the long-term effect of treatment of TMJ pain/dysfunction. *J. Oral Rehabil.* 11:289-297.
- Mejersjo, C., and Carlsson, G.E. (1983) Long-term results of treatment for temporomandibular joint pain - dysfunction. *J. Prosthet. Dent.* 49:809-815.
- Modica, R., Juliani, G., and Ragni, G. (1968) Analisi roentgenicinematografica del movimenti masticatori nella normocclusione ed in alcune disgnazie. *Mondo Odontostomat.* 10(2):213-234.
- Modica, R. (1969) Dinamica Funzionale della Mandibola Prima e dopo l'Applicazione di Protesi Dentairie Rimovibili. *Mm. Stom.* 18:631-643.
- Mohl, N.D. (1978) Neuromuscular mechanisms in mandibular function. *Dent. Clin. N. Amer.* 22(1):63-71.
- Moller, E. (1966) The chewing apparatus: An electromyographic study of the action of the muscles of mastication and its correlation to facial morphology. *Acta Physiol. Scand.* 69, Suppl. 280.
- Montgomery, R., Dryer, R.L., Conway, T.W., and Spector, A.A. (1977) *Biochemistry - A Case Oriented Approach.* The CV. Mosby Co. pp 228-235, St. Louis.
- Morimoto, T., Takebe, H., Sakan, I., and Kawamura, Y. (1977) Interdental thickness discrimination and mandibular position sense. *J. Dent. Res.* 56 (Special issue D):D164, (Abstract).
- Mulick, J.F. (1965) An investigation of cranio-facial asymmetry using the serial twin study method. *Am. J. Orthod.* 51:112.
- Myotronics Research Inc. (1977) *Mandibular Kinesiograph Instruction Manual.* Seattle, WA.
- Neill, D.J. (1984) Mandibular kinesiography. An assessment of two systems for monitoring mandibular movement. *Proc. Eur. Prosthet. Assoc.* 8:108.
- Niswonger, M.E. (1934) The rest position of the mandible and centric relation. *J. Amer. Dent. Assoc.* 21:1572-1582.
- Olsen, E.S. (1951) Radiographic Study of variations in the physiological rest position of the mandible in seventy edentulous individuals. *J. Dent. Res.* 30:5 17.
- Owall, B. (1978) Interocclusal perception with anaesthetized and unanaesthetized TM - joints. *Swed. Dent. J.* 2:199-208.
- Paolini, D.A. (1970) A study on the method of recording and the differences in maximal biting force between extremes of vertical types. Master's Thesis, University of Pittsburgh.
- Peterson, T.M., Rugh, J.D., and Mclver, J.E. (1983) Mandibular rest position in subjects with high and low mandibular plane angles. *Am. J. Orthod.* 83:318-320.
- Posselt, U. (1952) Studies in the mobility of the human mandible. *Acta, Odont. Scand.* 10:1-159.
- Posselt, U. (1968) *The Physiology of Occlusion and Rehabilitation.* Blackwell Scientific Publications. ed.2, p.24-68, Oxford and Edinburgh.
- Ranasjo, K., and Thilander, B. (1963) Perception of mandibular position in cases of temporomandibular joint disorders. *Odont Tijdsch.* 71:134-144.
- Remien, J.C., and Ash, M.M. (1974) Myo-Monitor Centric: An evaluation. *J. Prosthet. Dent.* 21:137-145.

- Rugh, J.D. and Drago, C.J. (1981) Vertical Dimension: A study of clinical rest position and jaw muscle activity. *J. Prosthet. Dent.* 45:670- 675.
- Sassouni, V. (1969) A Classification of skeletal facial types. *Am. J. Orthod.* 55:109-123.
- Schaerer, P., Stallard, R.E., and Zander, H.A. (1967) Occlusal interferences and mastication: An electromyographic study. *J. Pros. Dent.* 17, 438-449.
- Schudy, F.F. (1964) Vertical growth versus anteroposterior growth as related to function and treatment. *Angle Orthod.* 34:75-93.
- Selkurt, E.E. (1971) *Physiology*. Little, Brown & Co. ed 11, Boston, pp 685- 688.
- Silverman, M.M. (1957) Centric occlusion and jaw relations and fallacies of current concepts. *J. Prosthet. Dent.* 7:750-769.
- Stohier, C.S., Ash, M.M., Jr. (1985) Demonstration of chewing motor disorder by recording peripheral correlates of mastication. *J. Oral Rehabil.* 12:49-57.
- Storey, A.T, (1976) *Temporomandibular Joint*. Anderson, D.J., Mathews, B. (eds): Mastication. Bristol, John Wright, Ltd., pp 50-57.
- Story, A.T. (1985) The role of the temporomandibular receptors in jaw function. Lisney SJW, Matthews B. (eds.) *Current Topics in Oral Biology*. Bristol, University of Bristol Press.
- Suit, S.R., Gibbs, C.H., and Benz, S.T. (1976) Study of gliding tooth contacts during mastication. *J. Periodontol.* 47:331.
- Teasdall, R.D., Park, A.M., Languth, H.W., and Magladery, J.W. (1952) Electrophysiological studies of reflex activity in patients with lesions of the nervous system; disclosure of normally suppressed monosynaptic reflex discharge of spinal motoneurons by lesions of lower brainstem and spinal cord. *Bull. Johns Hopkins Hospital.* 91:345-256.
- Thilander, B. (1961) Innervation of the temporomandibular joint in man. *Trans Roy Soc Dent* 7:9-67.
- Thomson, H. (1975) *Occlusion*. Bristol, John Wright and Sons Ltd., pp 142- 149, 243-249.
- Troelstrup, B. and Moller, E. (1970) Electromyography of the temporalis and masseter in children with unilateral cross-bite. *Scand. J. Dent. Res.* 78, 425-430.
- Vallbo, A.B. (1971) Muscle Spindle Response at the Onset of Isometric Voluntary Contractions in Man. Time Difference between Fusimotor and Skeletomotor Effects. *J. Physiol (Load.)* 218:405-431.
- Vig, P.S., and Hewitt, A.B. (1975) Asymmetry of the Human Facial Skeleton. *Angle Orthod.* 45:125.
- Waysenson, B., and Salomon, J. (1977) Three-dimensional Recordings of Envelopes of Motion Related to Mandibular Movements. *J. Prosthet. Dent.* 38(1):52 -60.
- Werner, H. (1956) Is It Possible With Our Methods Today to Determine the Freeway Space? *Trans. Europ. Orthod. Soc.* 239-248.
- Wesberg, G.A. and Epker, B.N. (1981) Musculoskeletal Adaptation to Surgical Advancement of the Mandible. *mt.J. Oral Surg.* 10 (6):417-422.
- Wesberg, G.A., et al. (1981) Neuromuscular Adaptation to Surgical Superior Repositioning of the Maxilla. *J. Maxillofac. Surg.* 9(2):117-122.
- Wesberg, G.A., et al (1982) Autorotation of the Mandible: Effect of Surgical Superior Repositioning of the Maxilla on Mandibular Resting Posture. *Am. J. Orthod.* 81(6):465-472.
- Wesberg, G.A., and Epker, B.N. (1983) Comparison of Mandibular Rest Positions Induced by Phonetics, Transcutaneous Electrical Stimulation, and Masticatory Electromyography. *J. Prosthet. Dent.* 49(1):100 -105.

Winer, B.J. (1962) *Statistical Principles in Experimental Design*. McGraw- Hill Book Co., Inc. pp 298-374, 77-85, New York.

Woltjen, J.A., Timm, G.W., Waltz, F.W., and Bradley, W.E. (1973) Bladder Motility Detection Using the Hall Effect. *IEEE Trans. Biomed. Engin.* BME-20, 295-299.

Wood, W.W. (1987) A review of masticatory function. *J. Prosthet. Dent.* 57:222-232.

Yemm, R., and Berry, D.C. (1969) Passive Control in Mandibular Rest Position. *J. Prosthet. Dent.* 22:30-36.

CLINICAL STUDIES

INTRODUCTION

The use of the Myo-monitor in clinical dentistry dates from 1969, the mandibular kinesiograph from 1975, and the clinical EMG-1 from 1980. The scientific literature documenting the rationale for use of these modalities has been outlined previously in this report.

Additionally, clinical modalities that have been in use successfully for many years develop a body of anecdotal, case history, or protocol literature. Although by definition they are not controlled studies, these articles develop a rich resource for the practicing clinician. Following are some of the clinical articles published in professional journals regarding clinical experience with the Myo-monitor (low frequency TENS), mandibular tracking, and electromyography.

The American Dental Association directive "Programs of the Council on Dental Materials, instruments and Equipment" states, "Extended clinical experience when appropriate may be utilized as a basis for evaluation of the product." Following is a partial listing of such articles as they pertain to the modalities covered by this review.

ARTICLES REVIEWED IN THIS PUBLICATION**STUDIES THAT DOCUMENT THE USE OF THE MYO-MONITOR, MANDIBULAR TRACKING AND SURFACE ELECTROMYOGRAPHY IN CLINICAL DENTISTRY.**

1. Jankelson, B. Modern diagnosis and management of musculoskeletal dysfunctions of the head and neck. Diseases of the Temporomandibular Apparatus. 2nd Ed., C.V. Mosby Co., St. Louis, pp 59 1-199, 1982. See abstract page 196.
2. Jankelson, B. Neuromuscular aspects of occlusion: Effects of occlusal position on the physiology and dysfunction of the mandibular musculature. Dental Clinics of North America. Vol. 23, No. 2, April 1979. See abstract page 197.
3. Jankelson, B. Research endings and resultant management of craniomandibular (TMJ) symptom cluster syndrome. Proceedings of the Second International Prosthodontic Congress. C.V. Mosby, St. Louis, pp 291-194, 1979. See abstract page 198.
4. Jankelson, B. The Myo-monitor: Its use and abuse (I & II). Quintessence International, Vol. 9, Report 1601, No. 2, pp 1-11, 1978. See abstract page 199.
5. Jankelson, B. Three dimensional orthodontic diagnosis and treatment: A neuromuscular approach. J. of Clinical Orthodontics. Vol XVIII, No. 9, Sept. 1984. See abstract page 201.
6. Dinham, G.A. Myocentric: A clinical appraisal. The Angle Orthodontist. Vol. 54, No. 3, July 1984. See abstract page 201.
7. Callendar, J.M. Orthodontic application of the mandibular kinesiograph: Part I. J. of Clinical Orthodontics. Vol XVIII, No. 10. pp 710-718, Oct. 1984. See abstract page 204.
8. Callendar, J.M. Orthodontic application of the mandibular kinesiograph: Part II. J. of Clinical Orthodontics. Vol XVIII, No. 11. pp 791-805, Nov. 1984. See abstract page 205.
9. Dinham, R. Treatment of tic douloureux with Jankelson Myo monitor. J. Hawaii Dent. Assoc. Vol. III, No. 3, July 1970. See abstract page 206.
10. Vesanen, E. and Vesanen, R. The Jankelson Myo-monitor and its clinical use. Proc. Finn. Dent. Soc. 69:244-247, 1973. See abstract page 206.
11. Rogers, J.L. Patient's facial pain treated by Myo-monitor and dentures. Dental Survey. Vol. 56, p. 54, May 1979. See abstract page 208.
12. Larian, H.J. Instructive 16-year case report. Dental Survey. pp 87- 90, Sept. 1974. See abstract page 209.
13. Konzelman, J.L. Glossodynia: A case report. J. of Craniomandibular Practice. Vol. 3, No. 1, Dec. 1984-Feb. 1985, pp 82-83. See abstract page 211.
14. Karlson, R. Relief of TMJ syndrome: A typical case history. Dental Survey. p. 54, Sept. 1975. See abstract page 211.
15. Jach, E.T. Relief of myo-facial pain: Treatment of 5 patients. Dental Survey. pp 44-50, June 1975. See abstract page 212.
16. Keller, D.C. An anterior appliance for treating TMJ dysfunction. J. of Craniomandibular Practice. Vol. 3, No. 3, pp 251-266, 1985. See abstract page 212.
17. Haze, J.J. Overview of sleep disorders and the implication on dental practice. J. of Funct. Ortho. Vol. 4, No. 5, pp 15-17, 1987. See abstract page 213.
18. Hawkins, R. and Jackson, J. Mandibular physiologic neuromuscular position:, The neglected essential. J. Sleep Research. ed. Chase, McGinty, Crane; Univ. of Cal., Los Angeles, 1986. See abstract page 213.

19. Haze, J.J. Treatment of obstructive sleep apnea with the equalizer appliance. J. New Jersey Dent Assoc. pp 34-36, 1987. See abstract page 213.
20. Jach, E.T. The Jankelson Myo-monitor. Chicago Dent. Soc. DCS Review. pp 20-22, Jan. 1974. See abstract page 215.
21. Attanasio, R. A neuromuscular final impression technique for complete dentures. Comp Contin Educ Dent. Vol. IX, No. 8, pp 641- 644, 1988. See abstract page 216.
22. Cooper, B. Myofascial pain dysfunction: A case report. J. of Craniomandibular Pract. Vol. 6, No. 4, Oct. 1988. See abstract page 217.

Jankelson, B. Modern diagnosis and management of musculoskeletal dysfunctions of the head and neck. Diseases of the Temporomandibular Apparatus. 2nd Ed., C.V. Mosby Co., St. Louis, pp 591-199, 1982.

THE MYO-MONITOR

The Myo-monitor, specifically designed to accomplish relaxation of the mandibular musculature by stimulation of the fifth and seventh nerves (Jankelson and Sparks et al, 1975; Jankelson and Swaim et al, 1975), simultaneously relaxes the various mandibular muscles to their resting lengths. The resulting physiological rest position provides the indispensable reference from which to attain a neuromuscular (myocentric) occlusal position (George and Boone, 1979; Jankelson, 1973; Jankelson, Dent Clin 1979; Jankelson, Proceed Prosth Cong-"Dentures" 1979; Jankelson, Proceed Prosth Cong- "Cluster" 1979; Jankelson and Radke 1978).

USES OF THE MYO-MONITOR

To propel the mandible from rest position through the interocclusal (freeway) space to the position of myocentric occlusion. At intervals of 1 1/2 seconds, in response to the Myo-monitor stimulus, the muscles contract and propel the mandible on a relaxed isotonic trajectory through the freeway space to the position at which occlusion would be most favorable to be perpetuation of a relaxed neuromusculature (Jankelson, 1973; Jankelson, Dent Clin 1979). Propelling the mandible from rest position to occlusion under the influence of balanced, programmed stimuli bypasses the disruptive influence of proprioception that is present in central nervous system- -directed closure and eliminates variables induced by manipulation imposed on the mandible by the practitioner. The resulting myocentric occlusal position is a result of decisions made by the relaxed musculature itself.

To relieve facial pain. Transcutaneous electrical neural stimulation (TENS) is being increasingly used in various areas of the body for relief from pain. A rationale for this procedure was suggested by the gate control theory of Meizak and Wall (Jankelson, Dent Clin 1979) and now by the data regarding the excretion of endorphins- -large polypeptide opiate molecules- - which appear in the bloodstream following electrical stimulation. The Myomonitor is being used effectively as a palliative modality and an adjunct to the overall treatment of atypical facial neuralgia, headache, earache, ticlike pain, and tic douloureux (Jankelson, Proceed Prosth Cong-"Dentures" 1979).

To record skeletal relation at various degrees of mouth opening. The Mandibular Kinesiograph (MKG) (George and Boone, 1979; Jankelson, 1973; Jankelson, Dent Clin 1979; Jankelson, Proceed Prosth Cong-"Dentures" 1979; Jankelson, Proceed Prosth Cong. "Cluster" 1979; Jankelson, "Manual" 1980; Jankelson, Prosth Dent 1980; Jankelson and Swaim et al, 1975) was developed to electronically track mandibular movement and to record the skeletal relation of the mandible to the skull in three spatial dimensions, plus the fourth dimension of time. The additional capability to track vertical velocity of the mandible during opening and closing movements (Jankelson, Prosth Dent 1980; Jankelson, Unpubl 1981; Jankelson and Radke, 1978; Jankelson and Sparks et al, 1975; Jankelson and Swaim et al, 1975) not only provides an overall assessment of the functional status of the musculature but also diagnostically records and displays the presence of joint dysfunction, which occurs as interarticular disc displacement that interferes with untrammelled muscle movement (Farrar et al, 1979).

CLUSTER SYMPTOMS OF MUSCULOSKELETAL DYSFUNCTION OF THE HEAD AND NECK

In the past decade it has become generally recognized that the syndrome is not only a dysfunction of the TMJ complex but also that a cluster of symptoms going beyond that of joint pain and dysfunction characterize the condition. In addition to TMJ involvement, other manifestations of the syndrome might include acute and chronic tension headaches, neck and shoulder stiffness, earache, eustachian tube dysfunction and ear stuffiness, tinnitus, vertigo, atypical facial neuralgia, tic douloureux and ticlike pain (Dinham, 1970).

Any of these symptoms may exist alone or in combination with any of the others. Because of the varied and often opposing concepts of diagnosis and treatment, mandibular dysfunction is commonly regarded as a disturbance with multiple causes (Laskin, 1969; Lupton, 1969; Schwartz, 1955; Schwartz, 1959; Sutcher, 1966). Now, however, modern electronic computer science has uncovered a common cause for this cluster of symptoms, establishing them as variations of response to a common underlying factor.

NATURE OF THE MUSCULOSKELETAL HEAD AND NECK SYNDROME

The data clearly identify a classifiable disease entity and establish two basic aspects of the disease:

1. There is a skeletal malrelation of the mandible to the skull, mandated by proprioceptive dictation that the muscles hold the mandible on a distorted trajectory to accomplish closure to a malpositioned occlusion. The resulting distorted position of the mandible, held by the muscles under tension now malposes the condyles in the joint space (Jankelson, Unpubl 1981).

2. Neuromuscular hyperfunction, spasm, and myostatic contracture induced by the proprioceptive dictation hold the mandible on a deflected, muscularly unbalanced trajectory to accomplish intercuspatation to a three-dimensionally malpositioned occlusion.

In summary, in the syndrome of musculoskeletal dysfunctions of the head and neck: (1) the soft tissue disturbance lies primarily in the neuromusculature, ligaments, and tendons of the area, and (2) the bony, skeletal malrelationships, stemming from neuromuscular adaptation to malpositioned dental occlusion, change the relationships of the temporomandibular joints and their articular components.

SUMMARY

The diagnosis and treatment of musculoskeletal dysfunctions of the head and neck enter a new phase with the availability of high-technology electronic instrumentation. It enables the practitioner to derive objective, electronically measured data on which to base the diagnosis and by which to monitor progress of treatment. The data shed new light on the nature of the disturbance.

The new findings establish the nature and the specificity of the craniomandibular TMJ syndrome. The skeletal malrelationships here described affect the articular components, consisting of the occlusion and the temporomandibular joints. The soft tissue disturbance lies primarily in the neuromusculature.

Jankelson, B. Neuromuscular aspects of occlusion: Effects of occlusal position on the physiology and dysfunction of the mandibular musculature. *Dental Clinics of North America*. Vol 23, No. 2, April 1979.

In the past the common criterion for evaluating the desirability of an occlusal position has been the mechanical repetitiveness with which the position can be registered. The concern for this criterion is understandable when one considers the problem that faces the clinician when he must decide on an occlusal position for the patient who has become edentulous on one or both arches, or who has had the crowns reduced for reconstruction, or who has an existing occlusion that is giving him problems of dysfunction and discomfort.

However, an even more important criterion for evaluating the desirability of an occlusal position is its effect on the neuromuscular apparatus.

To develop an occlusion that is compatible with relaxed neuromusculature, it is necessary to first develop modalities to relax, normalize, and control the musculature of the jaw. Transcutaneous electrical neural stimulation (TENS) is firmly established in physical medicine as a most effective, physiologically rational means of relaxing specific areas of the musculature.

The Myo-monitor (Jankelson and Radke, 1978) was designed to adapt TENS specifically to the requirements for the relaxation and control of the complex of muscles involved in mandibular function. This is accomplished by the application of mile, timespaced programmed stimuli through the fifth and seventh nerves. Extensive laboratory measurement and clinical testing established that the Myo-monitor stimuli are indeed neurally conducted and are effective in relaxing mandibular musculature that is in a state of fatigue, excitement, tension, or spasm (Jankelson and Sparks et al, 1975).

In addition, transcutaneous electrical neural stimulation has the essential ability not only to relax the musculature, but also to initiate controlled isotonic muscle contraction to propel the mandible from rest position on an isotonic trajectory through the interocclusal space to a neuromuscularly oriented occlusal position in space

CENTRIC OCCLUSION

Centric occlusion can be described as the existing position of intercuspatation. In no case in our investigation did it coincide with centric relation. The data also established that centric occlusion may coincide with the neuromuscularly balanced position, but in a large proportion of cases, centric occlusion showed some deviation in one or more dimensions from the neuromuscular position. In those cases where centric occlusion was not compatible with neuromuscular relaxation, the degree of muscle tension was always further increased by retrusion.

The data show that centric occlusion, apparently by feedback to proprioceptors, is the dictator and controller of the posture and the skeletal relationship of the mandible to the skull. When centric occlusion does not coincide with the neuromuscular position, proprioceptive feedback from the malpositioned centric occlusion dictates and maintains strained muscle accommodation, and an accommodative trajectory of closure. The result is mandible dysfunction characteristic of craniomandibular (TMJ) syndrome.

MYOCENTRIC OCCLUSION

Rest Position is the clinical reference point from which myocentric occlusion is registered. Myocentric occlusion is that terminal point in space at which, with the mandible in rest position, subsequent isotonic muscle contraction raises the mandible through the interocclusal space along the myocentric (muscle balanced) trajectory. Myocentric occlusion often coincides with centric occlusion, but in no instance was myocentric occlusion found to coincide with centric relation. The registration of myocentric occlusion can only be performed by balanced, relaxed neuromusculature. Myocentric occlusion cannot be registered in the presence of interfering clutches, protruding members, a pantograph apparatus, or manipulation or guidance by the dentist.

SUMMARY

Centric Relaxation: Muscle strain and tension are required to achieve retrusion to centric relation. The data show that the conventional gnathologic armamentarium and procedures used to achieve a mechanical occlusion based on a retruded border position program tension into the musculature. The procedures are incompatible with maintenance of a relaxed musculature.

An existing centric occlusion that appears mechanically satisfactory when the teeth are in occlusion may be incompatible with a relaxed musculature. When such a centric occlusion was repositioned and corrected to the myocentric (neuromuscular) position, myocentric occlusion instantly became the patient's centric occlusion.

Myocentric (Neuromuscular) Occlusion: Registration of myocentric occlusion is achieved by isotonic muscle contraction that originates from rest position. Rest position becomes the launch pad from which subsequent isotonic muscle contractions lift the mandible on a relaxed trajectory through the interocclusal space to the position of myocentric occlusion. Achievement of this physiologic goal in every day clinical practice has now become a reality with the availability of appropriate instrumentation and development of practical clinical techniques.

Jankelson, B. Research findings and resultant management of craniomandibular (TMJ) symptom cluster syndrome. Proceedings of the Second International Prosthodontic Congress. C.V. Mosby, St. Louis, pp 291- 194, 1979.

Breakthroughs in understanding, diagnosing, and treating dysfunction of various parts of human body have always had to await the development of sensitive instrumentation capable of measuring minute body responses. The development and availability of the Mandibular Kinesiograph (MKG) has now brought to the dentist the capability provided by electronic instrumentation for retrieving, recording, and measuring data reflecting mandibular dysfunction. The capability to measure mandibular dysfunction and obtain objective data is now analogous to the capability of the cardiologist to measure cardiac dysfunction with an ECG, the neurologist to measure neurologic dysfunction with the EEG, or the myologist to measure and monitor muscle dysfunction with an EMG.

The data derived from these advanced diagnostic instruments have, in every field, led to the development of treatment instruments. Examples are the cardiac pacemaker and the various stimulators for muscle relaxation and, in neurology, for pain control. Similarly, a highly specialized stimulator, the Myo-monitor, has been designed to fulfill the unique requirements for simultaneous bilateral mandibular stimulation. The instrument uses transcutaneous electrical neural stimulation (TENS) through the fifth and seventh nerves, which control the complex of muscles involved in the function of the mandible. Extensive laboratory measurement and clinical use have established that the instrument is effective in relaxing muscle that is in a state of fatigue, excitement, tension, or spasm.

In a study of 100 consecutive craniomandibular (TMJ) patients monitored on the MKG, the data showed a common dysfunctional etiology for an associated cluster of symptoms. The patients typically complained of unilateral or bilateral facial pain, clicking, or crepitus in the temporomandibular joints, tension, soreness and stiffness of the associated musculature, and restricted, deviated mouth opening. (Headache, earache, ear stuffiness, tinnitus, and stiff neck are commonly associated symptoms which are often not reported to the dentist, except under specific questioning, because they are not commonly associated in the patient's mind as being connected to his immediate problem of mandibular dysfunction.)

In a 6-year study of over 400 people, the trace patterns on a Kinesiograph demonstrated the remarkable repetitiveness with which the mandibular muscles close the mouth to the intercuspal position of the teeth. The obvious interpretation of this consistent phenomenon is feedback from the occlusion into the craniomandibular proprioceptors and muscle spindles, with which a recent investigation showed this musculature to be richly endowed.

OCCLUSAL POSITION DICTATES THE ADAPTIVE HOLDING POSITION

One might assume that the muscles would relax to their resting position between closures. The MKG patterns, however, establish that this does not occur. Even after the muscles have been relaxed, a single closure to a malpositioned occlusion is sufficient to program the musculature to hold the jaw on or near a trajectory that is dictated by the necessities of entry into the malpositioned occlusion.

The data show conclusively that not only is the musculature unbalanced by the skeletal malrelationship (distortion) in the closed position, but also that when the mouth is open (at the adaptive holding position), the mandibular musculature remains in a programmed state of residual tension as dictated by the position of the occlusion. It is now apparent that there is a distinct physical basis in the form of muscle tension and skeletal malrelation without surcease, whether the mouth is open or closed. This accounts for what appeared to be excessive complaint, attributed to generalized, disturbed emotional states. While generalized emotional tension can be a significant contributing factor, it can also be a result of feedback to the reticular formation in the brain stem from the specific mandibular musculoskeletal disturbance. The administration of ataractic drugs for general, overall relaxation is a helpful adjunct in treatment to decrease systemic tension. However, their effect on the mandibular musculature specifically is offset by the proprioceptive reintroduction of tension that occurs each time the patient closes the mouth to occlusion.

TREATMENT

The basic treatment is to provide an occlusion situated on a relaxed, isotonic trajectory of closure from rest position to occlusion. The correction involved all dimensions; vertical, anteroposterior, and lateral.

Two primary factors determine the preferable mode of treatment: (1) whether, after the muscles have been relaxed, the interocclusal space exceeds 1.5 mm and (2) whether the degree of horizontal malpositioning would require excessive mutilation of the teeth by grinding.

SUMMARY

A specific underlying etiology for the craniomandibular syndrome is now emerging. It is characterized by muscle tension, spasm, and myostatic contracture induced by noxious proprioceptive feedback from a malpositioned occlusion. The articular component of the syndrome can be explained on the basis of resultant impingement of the condyles as they are pulled, by the imbalanced musculature, against the walls of the joint cavity, where nerve receptors are located. The ability to measure and control maxillomandibular relationships is essential to accurate diagnosis and consistent, successful treatment of the syndrome.

Jankelson, B. The Myo-monitor: Its use and abuse (I & II). Quintessence International Vol. 9, Report 1601, No. 2, pp 1-11, 1978.

THE MYO-MONITOR: ITS USE AND ABUSE (I)

INTRODUCTION

In recent years the dental profession has become clearly divided into two general concepts for determining the correct mandible to skull relationship at maximum intercuspal position. The condylar theory, more commonly referred to as the gnathologic approach, espouses the retruded, "terminal hinge & position (centric) relation and certain manipulated border movements as the determinants of occlusion, reproducibility being the only justification. No consideration is given to the tension and stress applied to the neuromuscular elements of the stomatognathic system by this approach. The neuromuscular theory, in direct opposition, states that muscle relaxation is prerequisite to obtaining an occlusal position that will in turn sustain a relaxed musculature, and that the level of residual tension within a voluntarily inactive musculature is inversely proportional to the overall health and functional efficiency of the entire system.

New advances in science have always had to await the development and availability of appropriate instrumentation. The advance of dentistry into neuromuscular occlusion is no exception.

The Myo-monitor was originally developed as a means of applying the neuromuscular approach to occlusion. The impetuses for development were: 1. the complete lack of any evidence that function or parafunction occurs at centric relation or along border pathways, 2. a realization that the T.M.J., like any other joint, does not originate but merely accommodates movement, and 3. an acceptance of the uniqueness of a given patient and the need for a technique capable of registering that uniqueness. Thus the Myo-monitor technique is an intra-systemic approach to occlusal positioning using the patient's own musculature and eliminating ambiguous, universal, and arbitrary criteria.

SCOPE

The objectives of this article are: 1. to clarify for the reader the physical characteristics of the Myo-monitor, 2. to review the various clinical diagnostic and treatment procedures that may be realized through its use, and 3. to reveal its susceptibility to abuse by persons untrained in its use.

THE NEURAL STIMULI

The Myo - monitor is a digital, electronic pulse generator specifically optimized for bilateral transcutaneous electrical neural stimulation (TENS) of the stomatognathic system (Jankelson and Sparks et al, 1975). The mechanism through which it functions is universally known to the physiologist but has only partially captured the awareness of the dental profession (Jankelson and Swaim, 1972).

The stimuli of the present model J-3 Myo-monitor are 500 microseconds in duration and continuously variable in amplitude from 0 to 25 milliamps maximum. A balance control allows the operator to adjust the relative strengths of the stimuli to the right and left sides for a balanced response. The stimuli are biphasic with a cathodic (negative) initial stimulating phase followed by an anodic (positive) discharge phase and occur at a fixed rate of 40 pulses per minute.

NEURAL STIMULATION

The Myo-monitor has been optimized for stimulation of the motor branches of the Vth and VIIth cranial nerves, bilaterally, using surface electrodes (Choi and Mitani, 1973). While some previous authors (DeBoever and McCall, 1972; Bessett and Quinlivan, 1973) reported failure in their attempts to record E.M.G. evidence of Myo-monitor-induced masticatory muscle contractions, except in the masseter, the more advanced E.M.G. recording techniques of Fujii and Mitani (Fujii and Mitani, 1973) have shown clearly the neural mediation of the stimuli, as have subsequent intensity-duration tests (Jankelson and Sparks et al, 1975). Thus, the muscle responding to the Myo-monitor stimuli include all of the muscles of mastication and facial expression.

THE MYO-MONITOR: ITS USE AND ABUSE (II)

RELAXATION OF THE NEUROMUSCULATURE

The most crucial technical error in utilizing the Myo-monitor is attempting to register myocentric position without first adequately relaxing the musculature by pulsing just above threshold amplitude for at least 30 minutes (Myo-monitor Instruction Manuals 1971, 1974, 1977).

In studies comparing repetitiveness of the gnathological centric relation position and the myocentric position, the sequence of the registrations becomes crucial. The registration of centric relation, even briefly done, excites the musculature. The excitement induced by the retrusion to centric relation then makes it impossible to register a myocentric position. Subsequent reduction of tension and relaxation of the musculature as shown in the Mandibular Kinesiograph (MKG) recording requires 30 to 40 minutes of subsequent Myo-monitor pulsing before proceeding with myocentric registration.

The ability of the Myo-monitor to produce repetitively accurate myocentric closure depends upon first achieving a relaxed muscular state. Investigators who did not include this requirement in the stated conditions of their experiments reported they were unable to obtain consistent results.

EDUCATION IN MYO-TRONIC TECHNOLOGY

With the advent of Myo-tronics, dentistry is being introduced to a new, advanced electronic system that provides improved capability for the management of mandibular function and dysfunction. A change of such significance requires that the researcher and the practitioner become proficient with the new methodology through education and by working in the field.

Jankelson, B. Three dimensional orthodontic diagnosis and treatment: A neuromuscular approach. J. of Clinical Orthodontics. Vol XVIII, No. 9, Sept. 1984.

The use of electronically derived measurements and objective, quantitative data to diagnose the functional status of the musculoskeletal system of the head and neck is a significant step forward in the evolution of orthodontics into a major orthopedic specialty.

Musculoskeletal dysfunction of the head and neck is often the primary etiology of a diverse group of symptoms such as TMJ dysfunction, headaches, myalgia, otalgia, cervicalgia, and neuralgias. (Cooper and Rabuzzi, 1984; Jankelson, Dent Clinics 1979; Jankelson, mt Prosth Cong "Cluster" 1979; Jankelson, 1972; Principato, 1982; DeBaisi and Neironi, 1982; Dinham, 1970; Gernet et al, 1980; Vesanen and Vesanen, 1973; Weiss, 1976; Wessbert et al, 1981; Bazzoti, 1983; Choi and Mitani, 1973; Schwartz, 1955; Thompson, 1971; Carlsson, 1981; Reik and Hale, 1981; Farrar, 1979; Gelb et al, 1978; DeSteno, 1977; Laskin, 1969; Mikhail and Rosen, 1980; Burton, 1969). Before beginning treatment, the orthodontist should consider musculoskeletal dysfunction as a possible cause of one or more of these symptoms or as a presymptomatic potential for future dysfunction (Cooper and Rabuzzi, 1984; Jankelson, 1982). Today's superior diagnostic capabilities can uncover and intercept presymptomatic musculoskeletal disease that could become acute and symptomatic under the added stress of orthodontic procedures.

Measurement for the diagnosis of existing musculoskeletal dysfunction in the orthodontic patient provides a needed additional functional diagnosis to complement the conventional use of cephalometric and TMJ x-rays. The electromyograph (EM2) and mandibular kinesiograph (MKG) respectively measure electrical activity of the muscles and the skeletal relation of the mandible to the skull. These data are essential for initial diagnosis, monitoring of treatment progress, and verification that a relaxed neuromuscular environment - - which is the goal of functional orthodontic treatment has been obtained for the finished case.

SUMMARY

Improvement of appearance is a primary motivation for patients seeking orthodontic treatment. However, every orthodontic patient is also a neuromuscular patient. Alleviation of the head and neck pain of musculoskeletal dysfunction must become an equally strong motivation for orthodontic care, as health-care professionals and the public become increasingly aware of its effectiveness and availability.

It is essential in the diagnosis of every patient, before instituting therapy, to derive precise, quantitative data that reveal whether the skeletal relation of the mandible to the skull is distorted or not, and document the extent of musculoskeletal dysfunction of the head and neck stemming from an existing malpositioned occlusion.

Structural diagnosis based on cephalometric and other x-rays gains in significance when supported by functional data of musculoskeletal status. The increasing emphasis on the orthopedic correction of skeletal malrelation of the mandible to the skull inevitably expands the scope and changes the image of orthodontic practice. As EMG and MKG data show, the significance of the orthopedic capability of orthodontics extends beyond the jaws along to the entire musculoskeletal system of the head and neck; and, as functional considerations become paramount, the orthodontist becomes the primary orthopedic specialist in treatment of head and neck pain.

Dinham, G.A. Myocentric: A clinical appraisal. The Angle Orthodontist. Vol 54, No. 3, July 1984.

With the development of the Myo-monitor by Jankelson (1975) about ten years ago, transcutaneous electrical neural stimulation (TENS) of the motor branches of the 5th and 7th cranial nerves became clinically usable. The objective of TENS was first to decondition or relax the mandibular and facial musculature in order to establish and identify the true mandibular rest position. Then, after the musculature was deconditioned or relaxed, the continuing impulses of the Myo-monitor could stimulate the musculature to raise the mandible from rest position through the interocclusal clearance (freeway space) to its correct vertical functional position.

A Postulate may be - defined as an essential presupposition, condition, or premise. The following postulates are offered as a basis for a rationale for the concept of myocentric relationship.

1. The mandibular musculature is the dominant factor in mandibular positioning.
2. Free mandibular movements start from and return to rest position.
3. The rest position of the mandible is a resultant of a physiologic neuromuscular state which is unique for each individual.
4. The rest position of the mandible is the most reliable starting point from which to evaluate mandibular movements.
5. The true relaxed rest position of the mandible may be different from the apparent rest position.
6. The mandibular musculature must be relaxed before a true rest position can be established.
7. The mandibular musculature can be relaxed by electrical transcutaneous neural stimulation to establish a true rest position.
8. Transcutaneous electrical neural stimulation can also be used to stimulate the relaxed mandibular musculature to raise the mandible from its true resting position through the interocclusal space to the myocentric position of the mandible.
9. The myocentric position of the mandible is the optimum neuromuscular relationship of the mandible to the skull with teeth in contact.

Most orthodontic casts are related by means of a tooth-guided wax bite registration. The patient is instructed to bite into a wax wafer which is used to orient the case for trimming. The resultant static tooth-guided relationship is based on voluntary action by the patient, with or without mandibular guidance or manipulation by the orthodontist.

Such a relationship may or may not show the truly relaxed relationship of the mandible to the maxilla, depending on whether the mandible deviated from a normal path of closure to avoid tooth interferences in its closing path.

Some orthodontists feel that unmounted orthodontic casts can be inadequate or even misleading. Wood (1977) asked "What do these diagnostic tools tell us concerning the relationship of the mandible to the maxilla? Is this a true occlusal relationship? Could there be a more meaningful way to achieve the information necessary to make an accurate and functional diagnosis...?" Roth (1973) stated that "It is obvious that currently used orthodontic diagnostic armamentarium do not relate the dentition to joint movement patterns on closure or during eccentric excursions." Graber (1961) has said "To relate cases in so-called centric occlusion is purely a static maneuver, arbitrarily selecting the terminal phase of the functional cycle because of the mechanical interlocking." Thompson (1951) has stated "It is now realized that a proper diagnosis is impossible except in the simplest case by merely occluding upper and lower casts in the hand and looking at individual tooth relations. It is generally accepted that the occlusal position of the mandible may not be the desired functional position."

APPRAISAL OF THE PROCEDURE

PRETREATMENT REGISTRATION

The questions to be resolved are:

1. Do you find out more about the problem? Does any added information justify the extra time and effort?
2. Does it help to decide whether to extract or not?
3. Should lateral cephalometric radiographs be taken with the mandible in the myocentric position?

1. DO YOU FIND OUT MORE?

In my opinion, using this procedure before treatment can be very valuable. Casts mounted with this procedure are at least as useful as the usual orthodontic cases, and quite possibly much more so. One can more easily see interferences, lateral and anteroposterior shifts, and vertical problems.

2. THE EXTRACTION DECISION

Functional analysis of these cases in the myocentric position before treatment could still be very valuable. If there is a possibility that single- arch extraction such as maxillary first bicuspids only, or closing spaces of missing lateral incisors, could contribute to a myocentric malocclusion, such procedures should be considered carefully.

3. CEPHALOMETRIC RADIOGRAPHS

The possibility of a diagnostic advantage in taking cephalometric radiographs with the mandible in the myocentric position was investigated in 14 cases.

MYOCENTRIC DURING TREATMENT

This procedure is valuable in checking arch correlations, closing deviation, lateral or anteroposterior displacements, dual bites, vertical discrepancies, and overall jaw relationships.

AFTER TREATMENT

Neuromuscular registrations were also made for 33 patients after active appliance therapy had been completed. Most of these patients were still under retention, but some had been without any appliances for several years. With their casts mounted in articulators at the myocentric position, some degree of myocentric malocclusion could be detected in all of them. Some were very close to the myocentric occlusal position, and others had mild malocclusions which were apparently well tolerated with no TMJ symptoms. These could usually be equilibrated.

There were also some more severe functional malocclusions that required further treatment with splints, bite plates or retaining appliances designed for minor tooth movements. According to the neuromuscular analysis, the teeth in these cases were too far from a myocentric occlusion for effective correction with equilibration alone.

Many of those cases would be considered acceptable as orthodontic results are usually judged. However, when they were subjected to a critical neuromuscular analysis certain functional discrepancies became apparent. Some of the more common discrepancies were:

- * Incisal interference causing posterior mandibular displacement
- * Excessive interincisal angles, usually associated with insufficient uprighting of incisors
- * Excessive anterior vertical overbite
- * Insufficient vertical height and lack of vertical support in the posterior areas when the mandible was at the myocentric position
- * Poor arch form correlation when the mandible was in the myocentric position
- * Various combinations of the above with posterior and/or lateral mandibular displacements

Some of those myocentric malocclusions were probably too minor for identification by examination of the usual orthodontic casts or by examination of the patient. These are often tolerated by the patient. However, when significant myocentric malocclusions are found, they should be treated (orthodontically, if possible) to establish an acceptable functional neuromuscular occlusion.

Callender, J.M. Orthodontic application of the mandibular kinesiograph Part I. J. of Clinical Orthodontics. Vol XVIII, No. 10, pp 710-718, Oct. 1984.

In our office, in addition to standard orthodontic records and tomograms, we do a mandibular kinesiograph (MKG) analysis on patients who present any of the following symptoms:

- * Joint noise or encumbered opening and closing of the jaws
- * Pain to palpation of the joint capsule and several muscles of mastication
- * Chronic ear problems
- * Poor rate of opening and closing the jaws
- * Diminished range of motion of the jaw (in three dimensions)
- * Various crossbites or septal midline asymmetries
- * Various tongue - swallow dysfunctions
- * Various airway problems
- * Apparent skeletal disproportions of the jaws
- * Various facial asymmetries

PRETREATMENT FUNCTIONAL ANALYSIS

Pretreatment jaw function is analyzed by recording typical jaw motions on the cathoderay screen. To understand abnormal MKG tracings, it is necessary to know the appearance of normal tracings.

The greatest value of an MKG is that it gives the operator electronically magnified eyes to view the stomatognathic system in function. As the operator gains experience, he can develop hypotheses for resolving dysfunction and observe their validity "live" prior to pursuing irreversible treatment procedures.

INITIAL ANALYSIS

The initial analysis of jaw function is made using these photographs together with study casts and pantographic, cephalometric, and tomographic x-rays. Hypotheses can be tested by observing the screen as the patient performs various jaw functions- -swallow, speech sounds, maximum opening and closing, stretch reflex, etc. Plans must be made to eliminate contributors to abnormal jaw function.

We often find it necessary to use a splint to negate proprioceptive influences. Psychic input .that is affecting jaw function can also be evaluated.

In my experience, very few young people have suffered pathologic alteration of the mandibular condyle, meniscus, or temporal fossa. It is common for them to have clicks and pops associated with entrapment of function of the joint parts. These alterations of joint function can be observed and measured on the MKG screen. They often can be correlated with abnormal positions of the condyle in the temporal fossa at centric or during translation of the joint as observed in tomograms. Their resolution should be planned during this analysis.

RECORDING MYOCENTRIC

After carefully analyzing all the factors involved- -joint condition, swallow reflex, airway, occlusion, etc. - -the doctor marks a point on the screen where he wants the jaw to be positioned. A photograph of the screen is made at this point, which reflects the condition of the musculature and the quality of muscle function at the time of registration. The technician then makes the acrylic index of that jaw position, and marks on the photograph the precise point at which the patient was directed during registration.

A point 1.5mm above physiologic rest is chosen to record the bite index. This is to be the eventual myocentric. The index is used for mounting one set of casts to be used during diagnosis. We routinely index within 0.25mm of our chosen point on the screen in all three planes of space. In cases of reciprocal click, it is extremely important that the point of index be on the path of closure at more jaw opening than the point of reciprocal click. We want to be sure the meniscus is recaptured by the condyle, and not displaced. This takes precedence over initially achieving myocentric, and it must be documented in the records to avoid confusion later on.

TREATMENT PLANNING

Information for treatment planning includes the patient's history, range of motion, and muscle palpation charts that are completed at the initial examination. All x-rays- -including tomograms of the joints- -are arranged for viewing on a large medical viewer so that they may be cross- referenced. Two sets of models are used- -one set oriented to the existing occlusion in the traditional orthodontic manner, and the other mounted on a Galetti articulator, using the MKG indices.

The notes made while observing the patient on the MKG screen and the photographs of the screen are also important, because they document the initial problems and qualify the MKG indices. The initial MKG index does not always represent the myocentric that we are trying to achieve. Although it is taken with the jaws closing on the trajectory dictated by the relaxed musculature, there are sometimes vertical interferences such as division 2 anterior tooth interference, tongue volume, airway demands, and collapsed dental arches with complicated occlusal schemes. The intention is to plan initial treatment with the best jaw position possible.

We use any procedure needed to achieve an unencumbered path of opening and closing of the jaws as demonstrated on the MKG, and we are careful that we have achieved myocentric before final treatment is planned.

Once a trustworthy MKG index is achieved, final treatment planning is undertaken to resolve the orthopedic and orthodontic problems. The concept is to treat to an MKG-defined jaw position and not to an existing centric occlusion. Incipient pathology may already be present in the joints.

Callender, J.M. Orthodontic application of the mandibular kinesiograph Part II. J. of Clinical Orthodontics. Vol XVIII, No. 11, pp 791-805, Nov. 1984.

CONCLUSION

This series of articles has introduced a concept of treating orthodontic cases in the vertical dimension to a determined rest-to-closure distance, with the occlusion set on a pathway on which the jaws are free to open and close without encumbrance and with relaxed musculature. This position is often at variance with existing dentric occlusion or with a centric relation achieved by the most distal positioning of the condyles. It is a stable post-treatment position, at which the condyles are well centered in the fossae.

This treatment does not discount current orthodontic concepts. It uses an additional diagnostic tool- -the MKG- -which allows visualization of the functioning jaws, and it cross-references this data with that of traditional orthodontic diagnostic techniques.

All the traditional orthodontic treatment modalities, along with the new concepts in functional appliances, are used to resolve functional problems. Functional appliances are fabricated to the jaw position indicated by the MKG. We have been able to create occlusions and jaw functions that are dramatically more free of pathology -producing dysfunction, and that have remained free of dysfunction for a number of years. The MKG is also used post-treatment to assure that functional goals have been achieved. Continued evaluation of completed cases demonstrates that the MKG-dictated resolution of orthodontic problems and TMJ dysfunction is efficient, stable, and economically viable.

Dinham, R. Treatment of tic douloureux with Jankelson Myo-monitor. J. Hawaii Dent. Assoc. Vol III, No. 3, July 1970.

The usefulness of the Myo-monitor in occlusal adjustment, complete prosthesis, reduction of post surgical trismus and swelling, full mouth rehabilitation, diagnosis and treatment of TMJ problems, can be readily understood. Undoubtedly there will be many clinical adaptations as yet not imagined.

Such a one is the case history presented here:

Japanese Female, Age 42 - - June 10, 1969:

Patient referred by endodontist because of limited opening and inaccessibility of upper right molar tooth for treatment.

Has had trifacial neuralgia for ten years (diagnosed by physicians) has had four alcohol injections, sinus surgery and lower third molar removed in September, 1968, empirically. Because of severe pain- -no relief- -referred to neuro-surgeon who injected alcohol in ganglion and diagnosed condition as a "tic."

Nov. 20, 1989:

Patient came in without appointment with excruciating pain on right side. All of the symptoms of a tic, sensitive to any kind of contact, almost fainting from the pain. I used the Myo-monitor only (no adjusting of occlusion) for one hour. (I also administered Zactirin.) After thirty minutes patient relaxed and actually fell asleep. At the end of an hour pain was completely gone- -patient was relaxed and comfortable. I continued the Myo-monitor for fifteen minutes more and Nov. 24, 1969 dismissed her.

Dec. 16, 1969:

Patient checked by telephone- -completely comfortable and free of pain.

CONCLUSION

Heretofore the usual treatment of "tic" facial neuralgia has been by painful injection of alcohol or severing the 5th nerve at the ganglion. If this were a true tic, perhaps this is the first time the Jankelson Myo-monitor has been used in its treatment. It most certainly opens a new avenue of clinical treatment of this most painful of afflictions.

Vesanen, E., and Vesanen, R. The Jankelson Myo-monitor and its clinical use. Proc. Finn. Dent. Soc. 69:244-247, 1973.

THE INSTRUMENT

The Myo-monitor (Jankelson, 1971) is an electronic instrument designed to generate an electric current corresponding to the natural nerve stimulus that produces muscle contraction in the body. It produces controlled current pulses adjustable between zero and 30 milliamperes. Pulses of 2 milliseconds' duration are provided at intervals of 1.5 seconds. The instrument is powered by four 1.5 volt flashlight batteries. The interval between pulses allows the muscles sufficient resting time between contractions, so that they can respond indefinitely without fatigue.

Contact with the patients is established with two electrodes placed symmetrically on the skin of the face, just in front of the tragus of the ears, and with the third opponent electrode placed at the nape of the neck. Through these electrodes the instrument provides simultaneous stimulation to the facial nerve and the trunk of the fifth nerve over the opening of the mandibular notch. After it has emerged from the skull through the foramen ovale. When properly adjusted, the pulse current produces repetitive contraction of all the muscles involved in mandibular movement, and guides mandibular closure to the correct occlusal position dictated by the musculature alone. It is important to understand that the muscles do not contract singly but all act simultaneously. Jaw closure is the result of contraction of a group of muscles.

REPORT OF TWO CASES

The two cases below have been selected from among the patients treated in the writers' private practice.

PATIENT NO. 1, FEMALE, AGED 56

March 10, 1969. The patient came for full dentures. She had had severe pain in the left side of the head for several years, mainly in the maxillary sinus region and behind the ear, with some occasional flow of mucus from the upper part of the throat. She had undergone two maxillary sinus operations, etc., in connection with which the teeth on the left side (upper and lower bicuspid, molars and upper cuspid) had been extracted. No relief of pain had been achieved. The parotid gland and ear had also been examined but nothing was found.

After consultation, it was decided to prepare a full upper immediate denture and lower partial. Bicuspid and molars were extracted from the right side. Impression taking was then postponed until the Myo-monitor was available.

Sept. 26, 1969: Impressions were taken with the aid of the Myomonitor. The patient felt great relief of pain when the instrument was operating and pleaded for longer treatment. She spent an extra 1/2 hour in the Myo-monitor.

Sept. 27, 1969: The patient returned with enthusiasm: the left ear had opened with a crackle on the way home the previous day. The patient had never told that her left ear had been almost deaf for about 2 years. Centric occlusion and vertical height were recorded with the Myo-monitor, and teeth selected.

Oct. 10, 1969: The immediate full upper denture and the lower partial denture were inserted.

During the following two appointments only very minor adjustments were necessary. All symptoms had disappeared and the patient felt happy and satisfied. She was requested to visit for rebasing after 2-3 months.

Nov. 3, 1969: The patient arrived without an appointment asking for Myo-monitor treatment. Trouble in the left ear had returned. She was treated with the Myo-monitor for about 1 hr. and felt relaxed.

Nov. 4, 1969: The patient was treated with the Myo-monitor for about 1 hr.

Jan. 10, 1970: Resorption was so small that only minor rebasing was necessary. At her request, the patient was again given Myo-monitor treatment.

Remarks: During the work with the Myo-monitor in Oct. 1969 one of the possible sources of the ear trouble was localized in the Eustachian tube area. Either the muscle tensor veli palatini was in spasm or the Eustachian tube was full of mucus. The patient was sent to an ear-nose-and-throat specialist for further examination. Nothing was found.

We did not hear from the patient for a long time and phoned to her in Jan. 1973. She felt happy and satisfied with the dentures, as before. Because of the ear trouble, she consulted another specialist. Careful examination revealed a small tumor, the size of a pea, at the orifice of the Eustachian tube. The benign tumor was removed.

However, this does not explain all the symptoms. Special attention should also be paid to the fact that of the muscles of the inner ear the stapedius muscle is governed by the facial nerve and the tensor tympani muscle by the trigeminal nerve. Besides, there is a close anatomic connection between the tensor veli palatini and tensor tympani muscles. Myrhaug (1970) has shown conclusively that functional disturbances in the biting muscles can be transferred to the muscles of the inner ear and vice versa. The Myo-monitor could be an important instrument for further study of the subject.

The case was reported in Nov. 1969 to Dr. B. Jankelson of Seattle, Wash., USA. It was the first of its kind.

PATIENT NO. 2, FEMALE, AGED 75

Nov. 16, 1972: Temporomandibular joint problem. The patient explained that she had difficulty in opening her mouth. The opening between the incisors was only 21 mm, a grating sound was heard from the joint on both sides and there was deviation to the right. There was a deep natural overbite. More vertical height had been lost, possibly after recent extraction of the lower first and second molars from both sides. Almost all the teeth were crowns and bridges, except the upper right second molar, the left first and second molars, and the lower left third molar. Both upper third molars and the lower right had been extracted long ago.

After 45 mm. with the Myo-monitor the opening of the mandible was 27 mm. The occlusion was checked, and bad premature contact was recorded on the left side between the upper second and lower third molars. This was eliminated. Besides, temporary amalgam fillings were made on the acrylic crowns to raise the vertical height about 1/2 mm. The patient felt relaxed.

Nov. 19, 1972: Opening 25 mm. The deviation had been overcome. After 30 mm. in the Myo-monitor the opening was 27 mm; after 45 mm 28 mm; and after 60 mm 30 mm.

Nov. 22, 1972: Opening 29 mm. After 0 mm. in the Myo-monitor 30 mm.

Nov. 23, 1972: Opening 29 mm. After 45 mm. 30 mm. The patient stated that during the treatment she felt thirsty and produced more saliva than usual. She had been suffering from a dry mouth.

Nov. 25, 1972: Opening 30 mm; after 60 mm 30 mm. The patient felt relaxed. The opening was not getting wider, but the result obtained was satisfactory to the patient, who commented that the opening had never been wide. For maintaining the present opening a lower partial denture was planned and made.

Remarks: The trouble had started with the loss of the lower first and second molars. All the crowns were already worn down and could not maintain the vertical height. The bite collapsed and the joints were forced to move backward, which caused muscle spasm. Bad premature contact on the left side developed at the same time. The opening between the maxillary and mandibular incisors became 9 mm wider after Myo-monitor treatment. The total opening between the incisors is still only 30 mm. But, considering that the depth of the overbite is 11 mm, the total opening of the mandible is 41 mm.

The seriousness of the case from the patient's point of view can be judged from our first consultation. She came with the x-ray diagnosis "ligaments of the styloid muscles are ossifying" and with oral information that nothing could be done.

Rogers, J.L. Patient's facial pain treated by Myo-monitor and dentures. Dental Survey. Vol 56, p. 54, May 1979.

On the morning of April 13, 1977, a 71-year-old white woman with a diagnosis of tic douloureux presented at my office. Pain, occurring on the right side of the face about four times a day for 30 or 40 minutes, was being triggered by eating, brushing the teeth, sneezing, touching the face, or air movement. Tic, which had begun in summer 1976 and gotten progressively more frequent, longer-lasting, and severe, had become excruciating.

A gynecologist had first diagnosed tic douloureux in September 1976. The patient had then seen an internal medicine specialist, who had confirmed the diagnosis and referred her to a neurologist for facial and skull x-rays. The only treatment mentioned had been to sever the involved fifth nerve, but the neurologist advised living with the pain rather than submitting to such severe surgery.

MYO - MONITOR THERAPY

I treated the patient in my office on April 13 with the Myo-monitor for 1 hour at T=1 (threshold +1). She reported one attack that afternoon, but with lessened severity and with duration of only about 10 minutes.

The following day, April 14, at the patient's insistence, treatment was for 2 hours at T +2. She reported no attacks that day.

Although I then requested that the patient wait for a further attack before additional treatment (to attempt to ascertain the duration of the relief that treatments were affording), she was so pleased by the pain-free day she had experienced that she requested another treatment the following day, April 15. I relented, and the patient once more received 2 hours of T +2.

There was no more pain reported until 4 days later, April 19, when the patient appeared in my office and reported that pain had "tried to start" that morning. T +2 was used for 2 hours.

Subsequently, a new upper denture and lower partial were constructed to the proper vertical dimension as determined by the Myo-monitor. As of this writing, the patient has been free of pain for over 1 year.

Lerian, H.J. Instructive 16-year case report. Dental Survey. pp 87-90, Sept. 1974.

Day after day we remain within the confines of our offices, practicing the same way we have practiced for years and convinced that our method of doing things is the best way. When we run into problems, we often solve them by trial and error. Nowhere is this approach more apparent than in the interpretation of such terms as centric relation, centric occlusion, rest position, freeway space and vertical dimension.

Within the isolation of his office each practitioner works out his own definitions and applies them in a method of treatment which appears to work most often for him. All is guesswork, and the dentist who guesses best has the fewest failures. He soon develops an innate sense of what is right and what is wrong - an innate sense based on such intangible factors as sight, touch, intuition and experience.

Is it any wonder, then, that it is so difficult for us to accept the fact that we might be wrong? This becomes even more difficult to accept when an impersonal electronic gadget appears to know more than we do.

The case history described here presents a most unusual set of circumstances occurring over a 16-year period for a single patient. During that time she was treated for severe temporomandibular pain, underwent parotidectomy twice, suffered severe alveolar bone destruction and received complete periodontal treatment. Finally, the patient underwent full mouth reconstruction, during which it developed that she had zero tolerance for TMJ dysfunction; in order to prevent recurrent TMJ pain, perfect occlusion had to be achieved.

The wide-ranging course of diagnosis and treatment proved most instructive, and point up some lessons for all practitioners.

To reestablish her centric and vertical relationships, we used an electronic instrument (Myo-monitor) developed by Dr. Bernard Jankelson. (The underlying principle is that use of this instrument allows the dentist to take control of the muscles of mastication away from the patient in order to achieve accurate occlusal registration. Using electrodes placed on the patient's face and a low voltage current, the dentist obtains 40 involuntary closures a minute.)

I employed the Myo-monitor again, ground away the occlusal surfaces of the temporary bridge until it was completely out of occlusion, and placed a thin mix of tooth-colored acrylic resin on the occlusal surfaces of this bridge. Rough edges were smoothed, but no attempt was made to alter the fossae or cusps that had been developed by the electronic readings.

The patient reported later in the day that all her TMJ symptoms had disappeared and she was quite comfortable.

One week later the patient returned to try on the ten-unit casting. Occlusal registration was taken electronically, the temporary bridge was replaced and the patient was dismissed.

The unit was mounted on an articulator, and processed at a laboratory. I noticed when it was returned that the upper and lower molars on the right side did not occlude completely. Years of experience and intuition had taught me that this could not be correct, so I assumed that the occlusal registration material had prevented the patient from closing completely.

I closed the occlusion a fraction of a millimeter until the molars occluded on the right side, and instructed the laboratory to complete the unit. In view of this patient's critical TMJ tolerance, I had the laboratory process the unit in plastic in order to simplify any necessary occlusal adjustments. One week later I seated the unit but did not cement it.

The patient called the next day and her TMJ symptoms were back in full bloom once again. I was ready to scream.

The patient came to the office, and she was in true agony. I ground the plastic out of occlusion, flowed a mix of cold-cure acrylic resin over the occlusal surfaces of the bridge, and made electronic readings of her occlusion. I smoothed off the rough edges and sent the patient on her way. The next day she was completely free of pain.

Now I was beginning to believe that the machine knew something I didn't.

The patient remained free of pain for a week, so I removed the plastic bridge, replaced it with the old temporary bridge, and sent the bridge to the laboratory to duplicate the plastic with porcelain - and without altering the fossae and cusps developed by the machine.

A week later the bridge was inserted but not cemented. Not a single adjustment was made to the occlusion. When the patient remained completely comfortable for a week, the bridge was cemented to place, in May 1972. To date, not one occlusal adjustment has been necessary.

Since this was unheard-of, I satisfied my curiosity by checking the original electronic occlusal registration on the articulator. It fit perfectly.

Because of my refusal to accept the original registration, I had put myself, my patient and my laboratory through a totally unnecessary ordeal.

We as practicing dentists must learn to accept the fact that our preconceived ideas may be wrong and that no procedure is infallible, regardless of how long we have used it.

Konzelman, J.L Glossodynia: A case report. J. of Craniomandibular Practice. Vol 3, No. 1, Dec. 1984-Feb. 1985, pp 82-83.

TREATMENT

Diagnostic therapy consisted of one hour of transcutaneous electric neural stimulation (TENS through transcranial leads in the area of the coronoid notches, with a cervical spine ground. (Please note that most conventional TENS units cannot be used transcranially. Two units that can safely be used in this way are the Myo-monitor (Myotronics, Inc., Seattle, WA), when used with a cervical spine ground, and the Pain Suppressor, a high frequency TENS.) The purpose of this treatment was to relax the muscles innervated by cranial nerves V and VII, which are accessible through the coronoid notch. The patient experienced complete pain relief which lasted for about 48 hours.

She returned in one week, and I again pulsed her muscles with TENS for one hour. At this visit, she was given a flat intraoral orthotic to disengage dental intercuspation and to permit a more relaxed mandibular muscle movement. Her glossodynia has not returned.

DISCUSSION

The early difficulty in making a diagnosis in this case may have been due to the presence of two distinct entities affecting the same anatomic area, both of which are relatively common. Benign migratory glossitis occurs in 1.4 to 2.4 percent of all patients examined, according to Shafer (1974). Glossodynia secondary to referred myofascial pain has been known and treated for many years by Funt (Funt, L.A., personal communication).

The current body of knowledge on pain referred from myofascial trigger points can explain some of the poorly understood "idiopathic" pain syndromes. For that contribution we owe considerable gratitude to Dr. Janet Travell (Travell, 1983).

Karlson, K. Relief of TMJ syndrome: A typical case history. Dental Survey, p. 54, Sept 1975.

I would like to share with other readers one of many typical case histories of patients who have been referred to our office by specialists in our area.

A woman complained of severe pain on the left side of her face. For 4 years she had been unable to open her mouth completely without great discomfort. She also had been examined by a neurologist, who suggested the possibility of exploratory surgery. Prior to this she had undergone acupuncture treatment in an effort to relieve the pain, but to no avail.

Since she had most of the systems of severe TMJ syndrome, we decided to use an electronic pulsating occlusal devise (Myo-monitor) which often can relieve such symptoms in 15 to 30 minutes. One of our assistants placed the electrodes in a position mesial to the lobes and applied a minimal threshold of current for 30 minutes.

After 30 minutes of minimal pulsation, I checked the patient's progress, and asked her to "open wide". When she did she smiled broadly and exclaimed, "This is the first time I have been able to open my mouth without pain in over 4 years." She even asked if she could take the device home with her.

The device restores normal muscle function in much the same way that normal contractions do, except that the normal function is inhibited by muscular accommodation to pain. The series of physical and chemical events require and exposure of 15 to 30 minutes of electrical stimulation before effects can be readily seen. Increased blood flow to the muscles and the flushing effect on the renewed lymphatic activity are the first steps toward normalizing the learned response to malocclusion and real joint disorders.

Proof of the memory accuracy of the neutralized musculature is demonstrated when taking impressions of lower occlusal registration. The outline maintains its sharpness after being hit over 100 times while paste impression material is setting. ...Before using such a device, of course, the operator should obtain thorough instruction in its use.

Jach, E.T. Relief of myo-facial pain: Treatment of 5 patients. Dental Survey. pp 44-50, June 1975.

One method I have found useful in determining the physiologic relationship of a denture involves the use of an electronic pulsating occlusal device that supplies an electrical impulse to the face. When electrodes are properly placed, one on each side of the face in front of the ear and on the posterior surface of the neck, branches of the fifth and seventh nerves are stimulated 40 times per minute, and the associated muscles are brought into function. This frequency produces the least fatigue in the muscles and theoretically can continue indefinitely without ill effects.

Then the instrument is properly adjusted, the mandible will rise from the relaxed open position to the top of the freeway space, in an anterior-posterior and lateral position that is most compatible with comfortable muscle function. (Vesanen, B., and Vesanen, R, 1973)

When the muscles are healthy and there are no obstructions to muscle action, the instrument can aid in establishing a functional maxillary- mandibular relationship, since the instrument-activated muscles bring the mandible to a specific reproducible position.

The instrument has been used to relieve muscle spasm; to equilibrate both natural occlusion and restorations to achieve muscle-balanced denture impressions, (Jach E.T., 1974) to relieve tic douloureux, (Dinham, R., 1970) trismus and post-surgical swelling; and to establish occlusal relationships in orthodontic therapy. The most satisfying and challenging applications I have found have been those involving myo-facial pain.

The foregoing examples certainly are not typical and the results are not always as quick or dramatic, but they do illustrate the benefits of muscle balanced occlusion. It is a comfort to operate knowing that the muscles have dictated the position of the mandible for optimal function. But as with all instruments, the pulsating instrument is a tool which is useless unless coupled with the knowledge, experience and ability of the dentist.

Keller, D.C. An anterior maxillary appliance for treating TMJ dysfunction. The Journal of Craniomandibular Practice. Vol 3, No. 3; 1985.**ABSTRACT**

The method of treatment described in this article first establishes a physiological mandibular position and then maintains this functional position throughout treatment. (This may involve conventional banded orthodontic techniques or passive eruption.) This system was specifically designed for treating patients who have TMJ dysfunction. The author presents case histories illustrating the corrections of a number of TMJ problems involving different stages of dysfunction. This system provides the practitioner with an option that can be incorporated easily into existing treatment modalities with little additional cost to the practitioner or the patient. It also offers positioning and precision that is not always available in other systems.

ADVANTAGES OF THE SYSTEM

The goal of this system is to properly position the mandible in relation to the maxilla and to approximate the dentition so that the TMJ assembly can function normally, the muscles of mastication have a normal physiologic motion, and the dentition occludes in the proper relationships with adequate lateral and protrusive protections. By establishing the desired end-of-treatment mandibular position first, the teeth can be approximated in harmony with the muscles of mastication. In TMJ dysfunction patients, this system can maintain the final splint position and allow dental approximation orthodontically or orthopedically. In orthodontic patients, the system can help reduce the chances of posttreatment TMJ problems, and it can also be used to intercept and correct potential TMJ problems.

The most important step in this technique is establishing the proper mandibular position. This can be accomplished with equipment such as a Myomonitor, a Mandibular Kinesiograph, or an Electromyograph, or with tomographs, splint therapy, kinesiography, TMJ radiographs, or other means. Once the position is established, the appliance described here will help to maintain it throughout treatment.

CONCLUSION

This article illustrates a TMJ orthodontic system that can be used to help intercept and correct potential temporomandibular joint problems. It also shows how this system is being used to treat patients with active TMJ problems. This system should not be seen as an end-all cure, but simply as one step in TMJ treatment.

I feel that this system can help to intercept many potential temporomandibular joint problems by establishing the proper end-of-treatment mandibular position and then correcting the occlusion to meet this desired position. The precision that the system offers allows the practitioner to use orthopedic and orthodontic treatments for a greater range of potential problems.

I have found no conclusive evidence that the system described here is potentially better than a combination of other orthopedic and orthodontic systems. However, this system allows a number of various treatment principles to be used simultaneously, which can help decrease the period of therapy while increasing the end-of-treatment precision. It is up to each practitioner to review the information presented in this article and draw his or her own conclusions regarding its values.

Haze, J.J. Overview of sleep disorders and the implication on dental practice. The Functional Orthodontist. Vol 4, No. 5; 1987.

INTRODUCTION

The recognition of the existence of Sleep Disorders has brought about rigorous investigation by medical, dental and allied health professionals. Dental practitioners should be aware of the general signs and symptoms of Sleep Disorders, treatment approaches, relationships to dental care and available treatment for sufferers.

NON-SURGICAL TREATMENT OF OBSTRUCTIVE SLEEP APNEA WITH THE EQUALIZER APPLIANCE.

Equalizer Appliance is constructed by using neuromuscular principles for positioning the mandible. Sophisticated electronic instrumentation (EMZ Computerized Mandibular Scanner, are available from Myotronics Research, Inc.) is utilized in order to, determine the correct position along the trajectory of Isotonic closure of the mandible from physiologic rest through free-way space to fabricate the appliance. The use of this position, as determined by the Computerized Mandibular Scanner, will satisfy the need for providing the proper spatial relationship between anatomic parts by supporting the craniomandibular and pharyngeal musculature, and thus enhancing airway potency. The tongue is discouraged from posterior collapse by the increased tone of the Genioglossus muscle which is effected by mandibular positional change.

Hawkins, R., and Jackson, J. Mandibular physiology neuromuscular position: The neglected essential. Sleep Research, Vol 15; Brain Information Service/Brain Research Institute; University of California, Los Angeles; 1986.

ABSTRACTS

To reestablish the physiologic neuromuscular relationship of the mandible to the cranium, nervi V and VII (trigeminal and facial) are stimulated with low frequency electrical current. In contrast to the existing pathologic position of the mandible, a new position devoid of muscular imbalances is attained. This new position is firmly recorded with an electronically based procedure known as myoregistration. From this myoregistration, an intraoral orthotic may be fabricated to maintain this physiologic position. (Jankelson, B. 1979.)

To advantage the candidate for UPPP with this technology, the following procedure may be followed:

- (1) Lateral headfilm with mandible in acquired (habitual) relationship with cranium. Measurements recorded for PAS and Hyoid space.
- (2) Lateral headfilm with myoregistration in place intraorally. Measurements recorded for PAS and Hyoid space.
- (3) If an augmentation of PAS occurred yielding an excess of 10 mm. of PAS and a diminution of Hyoid space occurred yielding a measurement of less than 20 mm., the candidate has a favorable prognosis.

This study utilized cephalometric roentgenograms of five person. Each person had two headfilms, one with the mandible in habitual relationship and a second with the myoregistration in place. Tracings and measurements were obtained for each roentgenogram to demonstrate the millimetric changes in the posterior air space and the hyoid space.

It was noted that as the distance increases from the mandibular symphysis to the posterior wall of the pharynx, the hyoid is elevated and the tongue is carried forward by its attachment to the superior mental spine via the genioglossus thus concomitantly increasing the posterior air space. These events are routinely observed in the electronic establishment of the mandibular physiologic neuromuscular position, the notable exception being Angle's classification III which denotes mandibular prognathism.

Haze, J.J. Treatment of obstructive sleep apnea with the equalizer appliance. Journal of the New Jersey Dental Association. 1987.

Three types of sleep apnea are recognized with polysomnography; 1) obstructive upper airway apnea; 2) central apnea, which is secondary to a cessation of respiratory effort; 3) mixed sleep apnea, which is basically a combination of central and obstructive. Many patients show a combination of all three types of apnea; however, by far the most cases of sleep apnea are of the obstructive type.

The Equalizer Appliance is constructed at myocentric occlusion which is determined by using sophisticated Instrumentation developed by Myotronics Research Inc. These Instruments are: the myomonitor, the bioelectric processor and the computerized mandibular scanner. The myomonitor is a transcutaneous electroneural stimulator, the bioelectric processor is a electromyographic instrument and the computerized mandibular scanner is a three-dimensional mandibular jaw movement tracking device.

Patient selection is very important for successful treatment with the Equalizer Appliance. The following outline services as and overview of treatment planning aids and factors to consider in case selection:

TREATMENT PLANNING AIDS

- A. Patient History
- B. Clinical Exam
- C. Diagnostic Casts
- D. Radiograph: Cephalometric, full Mouth Series, Panorex, Transcranial (six views).
- E. Electromyography: 8 channels (Temporalis Anterior and Posterior, Masseter, Digastrics)
- F. Computerized Mandibular Scanning
- G. Myocentric Bite Registration
- H. Muscle Palpation and Temporo-mandibular Joint Auscultation.
- I. Polysomnography Report
- J. Otolaryngological Evaluation

TREATMENT PLANNING FACTORS

- A. Patient's Psychological Profile
- B. Patient's Motivation, attitude, and Ability to be Compliant
- C. Periodontal support and health
- D. Cranio Mandibular Functional Assessment
- E. Nasal Airway Requirements
- F. Skeletal Problems

- G. Definitive Treatment Alternatives (Prosthetics, Orthodontics, Orthognathic Surger, etc.) must be considered.

The body of information on sleep disorders is growing rapidly. The impact of dentistry on the complete treatment of these sufferers is only of late being recognize, the future contribution by dental practitioners is being sought out due to the high success rate of treatment utilizing the Equalizer Appliance.

Jach, E.T. The Jankelson Myo-monitor. Miniclinic. ed. Venezia, A., reprinted from CDS Review, pp 20-22; 1974.

Dr. Jach has found the Myo-Monitor and its associated conceptual approach to the establishment of a physiologically balance, musculature- oriented relationship of the maxillary and mandibular arches to be a valuable ancillary to his clinical dental practice. Dr. Jach stresses that the machine is a tool whose value and employment is limited by the operator's knowledge, talent, and interpretation.

The Jankelson Myo-Monitor is an electronic instrument that has completely changed the method of dental practice for many of us.

It is a conversion from the mechanical-anatomical concept of dental practice which has dominated for some many years to an electronic- physiological approach.

The Myo-Monitor itself is an electronic instrument which stimulated the fifth and seventh nerves and the corresponding muscles. This is accomplished through paste-on electrodes that are applied to the face and relay the electrical stimulus through the skin to the nerves.

A question always arises concerning centric occlusion and centric relation as applied to the Myo-Monitor. The relationship is strictly of historic interest since they are meaningless in this technique which records a dynamic, functional position instead of a static anatomical one. Experience has shown that this position is most comfortable for the muscles of mastication.

Dentures made using the described technique have been the best fitting and least troublesome of any technique I have used. This observation has been common among Myo-Monitor users.

Denture construction is only one of many uses for the concept of Myotronics. Techniques have been developed for full mouth reconstruction, treatment of Myofacial Pain Syndrome (T.M.J.) and occlusal equilibration. Oral Surgeons have reported using the instrument for relief of trismus and reduction of post surgical swelling; Orthodontists have told me they use the "mate Position" as the goal to work toward in their cases, and last but not least case of Tic Douloureux have been successfully treated with the MyoMonitor.

Will all of the foregoing I do not in any way want to give the impression the Myo-Monitor is an Electronic Dentist, and the only talent needed is an educated finger to flick the switch on and off. It is an instrument associated with a philosophy of Dentistry that when combined with the knowledge, training, and talent of the operator can make the practice of Dentistry more enjoyable and less troublesome for the dentist and more comfortable and more comprehensive for the patient.

Attanasio, R. A neuromuscular final impression technique for complete dentures. *Compend. Contin. Educ. Dent* Vol IX, No. 8.

FINAL IMPRESSIONS

In essence, the final impressions will be made in two phases. Phase I will be responsible for the initial refinement and muscle trimming of the acrylic custom trays by identifying areas of excessive tray pressure in the denture-bearing areas as well as by identifying the peripheral extension and thickness of the trays. Phase II will be responsible for refining the phase I impressions with a corrective wash.

A low - frequency transcutaneous electrical neural stimulation (TENS) unit, the Myomonitor, is used to muscle-trim involuntarily the impression material in the custom trays to their proper neuromuscular extension and thickness. By placing the myotrode patches over the preauricular sigmoid notch area bilaterally, it is possible to stimulate the facial and trigeminal nerves. (Choi, B., 1973; Williamson, E., 1986) In this way, all of the muscles innervated by these cranial nerves will be stimulated, including the vestibular muscles. This is clinically evident by observing these movements during the stimuli.

Before the impression making, the patient should be pulsed with the low-frequency TENS unit for approximately 15 to 20 minutes at an amplitude that produces a mandibular rise or "kick" of 0.5 mm. to 1.0 mm with each pulse every 1.5 seconds. the amplitude that results in this mandibular rise is called the clinical threshold-old. (Jankelson, B., 1978) It has been shown that TENS will relax and not fatigue the musculature as long as the frequency is 60 impulses/mm or fewer. (Dixon, H., 1967) The efficacy of neural stimulation of the fifth and seventh cranial nerves using low frequency TENS has been documented. (Jankelson, B., 1975)

For the phase I impressions, the Myoprint is mixed in a ratio of 2.5 parts polymer to 1.0 part monomer. After attaining a smooth consistency, the material is loaded in and around the peripheries of the mandibular custom tray. The tray is inserted into the patient's mouth and is oriented over the supportive tissues. Light pressure is then placed on the finger guides, and the TENS amplitude is increase to the clinical threshold +50% until the fingertips detect a firm "kick" caused by the mandibular movement of each impulse. For example, a clinical threshold amplitude reading of "2" on the instrument dial will require an impression amplitude of "3".

By increasing the amplitude, the muscles in the buccal and labial vestibules as well as those in the floor of the mouth will contract with each pulse of the TENS unit, thereby custom muscle-trimming the impression material.

CONCLUSION

This article has presented a neuromuscular technique for making complete denture final impressions in which the oral tissues are reproduced with all of their muscle attachments in a position of function that would be compatible with comfort for the patient during speech, deglutition, and mastication. By using a low-frequency TENS unit to stimulate both the facial nerve and the mandibular branch of the trigeminal nerve, the clinician uses the contraction of the muscles in the vestibules, across the palate and hamular notches, and in the floor of the mouth to muscle-trim the impression and mold the flange extension and thickness. In this way, the clinician can avoid using any hand-manipulative border-molding methods that would not be representative of a true neuromuscular condition.

"Overtugging" may result in an underextended flange. Also, low-frequency TENS allows the practitioner to muscle trim areas such as the posterior palatal border, the hamular notches, and the buccal fold aspect of the tuberosities since the muscles involved are innervated by the motor branch of the trigeminal nerve.

Cooper, B. Myofascial pain dysfunction: A case report. J. of Craniomandibular Pract Vol 6, No. 4, Oct. 1988.

ABSTRACT

This article follows the case of a 16-year-old female in whom myofascial pain dysfunction was precipitated by the physical trauma of a bicycle accident, ultimately resulting in a maximum interincisal opening of 8 mm. The practitioner's therapeutic goal was to fully relax the musculature and reposition the mandible with an anatomically accurate orthotic to maintain optimal muscle function without accommodative function.

CASE REPORTS

In this case, my patient was a 16-year-old girl pre-disposed to MPD. She had been referred by her pediatrician and otolaryngologist after a bicycle accident precipitated myofascial pain dysfunction. Nine months prior to my examination, the patient had fallen off a bicycle, head first over the handlebars, hitting the left side of her face. She experienced pain in the left side of her face and ear, and several physicians and dentists examined her in the ensuing months. Treatments included endodontic therapy for a left mandibular molar thought to be the cause of her pain, and eventually extraction of the tooth was followed by extraction of two maxillary molars on the same side.

Electromyography was done on the anterior temporalis, masseter, and diaphragmatic muscles. Results showed moderate above-normal resting levels and poor clenching ability. Pretreatment data show weak functioning levels in both temporalis muscles and no output (Below the instrument's 16 uV threshold) from the masseters. An electronic three dimensional study of jaw movement was performed on a Mandibular Kinesiograph (MKG). The patient's velocity before treatment was 25mm/second on opening and closing (normally >250 mm/second) and she opened 8 mm maximum. On the same day, I used transcutaneous electrical neural stimulation for 10 hours to relax her facial muscles. Afterwards, I inserted an orthotic appliance over her lower teeth to maintain temporarily the improved muscle function achieved by TENS and to allow her to function in a neuromuscular occlusion. Maximum opening at that time was 11 mm. In the weeks that followed, the pediatrician treated the patient's drug dependency while I repeated the TENS therapy and used the orthotic to reduce muscle spasm and pain. ACT scan of the TMJ revealed no evidence of destructive process in the TM joints, demonstrated well-aerated paranasal sinuses, and showed intact middle - ear structures.

During the next five months, I monitored her muscle function and the accuracy of the neuromuscular orthotic electronically. A series of orthotics was made during this period as increasing muscle relaxation permitted greater accuracy in the occlusal position being established. My therapeutic goal was to fully relax the musculature and reposition the mandible with an anatomically accurate orthotic in the neuromuscular occlusal position to maintain optimum muscle function without accommodative function. TENS was used extensively throughout this period.

Major improvement was achieved by the end of the second month, demonstrated by pain reduction and a maximum interincisal opening of 24 mm.....

When I examined her at the end of that two weeks, I measured her maximum interincisal opening at 40 mm. Mandibular Kinesiograph testing recorded maximum velocities of mandibular movement in opening and closing of >300 mm/second and documented a healthy maximum opening, as observed clinically. Her occlusal position, established by the orthotic appliance, was on neuromuscular trajectory, with 1 mm vertical freeway space from rest to occlusion, verified by MKG analysis. EMG recorded healthy resting levels for the muscles tested and excellent compressive force on voluntary clenching with the orthotic appliance in place. The patient appeared to be in excellent health. She reported that painful symptoms were gone except for slight discomfort still felt around the left angle of the mandible, which subsequently disappeared.

In order to establish a healthy long-term occlusion, we performed a passive eruption procedure, uncovering the most posterior tooth on each side of the mouth by cutting away the orthotic's acrylic so that the neuromuscular occlusal position would be maintained by the remainder of the orthotic. When her exposed teeth had erupted into the neuromuscular position, we sequentially uncovered the next ones, bilaterally. This procedure can take two or more years, depending on eruption speed. Orthotic appliances are replaced as they lose essential occlusal accuracy following attrition. Eventually, all the teeth occluded neuromuscularly, eliminated the potential for MPD to recur. The patient has been symptom-free for three years following therapy.

FOREIGN ARTICLES

All dental universities in Japan and most medical/dental universities in Italy have pioneered the use of biomedical instrumentation for clinical and research purposes. This instrumentation is used in many other countries abroad in universities as well as in private clinics. Foreign researchers publish a substantial number of articles annually concerning biomedical instrumentation for occlusal evaluation, aids in TMD/MSD diagnosis and treatment, and other research. Many of these articles are published in English in U.S. or international journals and, if so, will be found elsewhere in this collection. The following bibliography is just a sample of some of the articles published in foreign languages.

Arizumi, K., Yamauchi, M., and Kawano, J. Masticatory muscle activity and jaw movement before and after treatment of temporomandibular joint-pain dysfunction - patient with reciprocal clicking and using anterior repositioning splint. The First Department of Prosthodontics, Asahi University, School of Dentistry.

Boschiero, R., Fraccari, F., and Pagnacco, O. Sindrome algico-disfunzionale dell'articolazione temporo-mandibolare. Estratto da *Minerva Stomatologica*, Vol. 35, No. 4, pp 339-356, April 1986.

Boschiero, R., Fraccari, F., and Pagnacco, O. Analisi dei risultati dell'uso del Myo-monitor in pazienti con ridotta apertura del cavo orale. Estratto da *Minerva Stomatologica*, Vol. 35, No. , pp 857-864, Sept. 1986.

Castroflorio, T., Talpone, F., Deregibus, A., Piancino, M.G., and Bracco, P. Effects of a functional appliance on masticatory muscles of young adults suffering from muscle-related temporomandibular disorders. *J Oral Rehabil.* Jun 2004. 31(6):524-9.

Choi, B. On the mandibular position regulated by Myo-monitor stimulation. *J. Japanese Prosthetic Dentistry*, Vol. 17, pp 73-96, 1973.

Coronelli, E., and Lasagna, M. L'elettromiografia nella pratica odontoiatrica. Suo ruolo nella diagnosi e nella terapia. Estratto da *Odontostomatologia & Implantoprotesi*, Feb. 1986.

Eble, O.S., Jonas, I.E., and Kappert, H.F. Transcutaneous electrical nerve stimulation (TENS): its short-term and long-term effects on the masticatory muscles. *J. Orofac Orthop.* Vol. 61. No. 2, 2000

De Biase, S., Neroni, P., and Sesenna, E. Valutazioni kinesiografiche dopo correzione chirurgica di un morso incrociato laterale. *Mi Stom.*, Vol. 35, pp 181-190, 1986.

Fraccari, F., Bogini, A., and Bertele, G.P. Vabutazione dell'equilibrio muscolare pre e post-chirurgico in soggetti affetti da microgenia. Estratto da *Minerva Stomatologica*, Vol. 35, No. 3, pp 147-157, March 1986.

Fraccari, F., Mariotto, R., and Bogini, A. Riabilitazione protesica mediante Guida neuro-muscolare di un raro caso di sindrome di christ-simmens-weech. Estratto da *Dental Cadmos*, pp 71-77, May 1986.

Fraccari, F., Bogini, A., and Tsamis, J. Bruxismo: riabilitazione e controllo in base a principi neuro-muscolari. Estratto da *Minerva Stomatologica*, Vol. 37, No. 4, pp 247-254, April 1988.

Izotani, Y. The clinical significance of the mandibular position regulated by myopulses. *J. Japanese Prosthetic Dentistry*, Vol. 24, No. 3, 1980.

Kawazoe, T. Effect of Myo-monitor pulsing on jaw opening in patients with trismus. *J. Gifu Dent. Assoc.*, Vol. 15, No. 1, pp 159-169, 1983.

Lasagna, M., and Orland, C. Modificazione dei flussi ematici muscolo-cutanei indotta dalla stimolazione neurale transcutanea-ischemia e dolore della patologia occlusale. Estratto da *Odontostomatologia e Implantoprotesi*, Jan. 1986.

Losert-Bruggner, B., Dudek, B., and Hülse, M. Wenn Schmerzen nicht schlafen lassen (Articles in German) Teil 1. *AZN* Jan 2007: 20-25 und Teil 2. *AZN* Feb 2007: 16-19

Losert-Bruggner, B., Schöttl, R., and Zawadzki, W. Neuromuskulär ausgerichtete Bisslagebestimmung mit Hilfe niedrigerfrequenter TENS-Therapie. "Determining the neuromuscular mandibular position by use of low frequency TENS." (Article in German) *GZM – Praxis und Wissenschaft* 8. Jg. 1/2003.

- Minagi, S., Matsunaga, T., Shibata, T., and Sato, T. An appliance for management of TMJ pain as a complication of Parkinson's Disease. *Jnl of Craniomandibular Practice*, January 1998, Vol 16. No.1
- Onizaka, K., Ochiai, S., and Kajiyama. The use of Myo-monitor in treating the temporomandibular joint syndrome. *J. Kyushi Dental Assoc.*, pp 55-64, 1984.
- Pantaleo, T., Prayer-Galletti, F., Pini Prato, G., and Prayer-Galletti, S. Effects of transcutaneous electrical nerve stimulation and of acrylic splints on jaw muscles activity in patients with myo-facial pain dysfunction syndrome: an electromyographic study. *Istituto di Fisiologia, University of Florence*, 1986.
- Preston, J.D., Blatterfein, L., Smith, F. *Glossary of Prosthodontic Terms, Fifth Edition*. *J. Prosth Dent*, 1987, p. 15
- Prinz, J.F. Characterization of sounds emanating from the human temporomandibular joints. *Arch Oral Biol*, Jul 1996 41(7):631-9
- Sasaki, H., Suzuki, K., and Doi, Y. The longitudinal inspection of cases finished by neuromuscular prosthetic treatment. *Sapporo City*.
- Tollaro, I., Bergamini, M., Antonini, A., and Vichi, M. La valutazione kinesiografica nella diagnosi ortognatodontica. *Estratto da Mondo Ortodontico*, May 1984.
- Torigoe, N., Yasahira, K., Yamani, T., and Yamashita, A. Analysis of the mandibular movement, Part 3, Normal opening-closing and maximum opening-closing after myopulsing. *J. Okayama Dent. Assoc.*, Vol. 3, No. 1, pp 51-57, 1984.
- Yamani, T., Yamashita, A., et al. Analysis of the mandibular movement, Part 4, Mandibular rest position and latercuspal position after myo-pulsing. *J. Okayama Dental Assoc.*, Vol. 3, No. 1, pp 89-95, 1984.
- Yainashita, A., et al. An analysis of the mandibular movement at the incision inferious of toothed adults without complaint of temporomandibular joint dysfunction syndromes. *J. Okayama Dent. Assoc.*, Vol. 1, No. 1, pp 25-31, 1982.
- Yamashita, A., et al. Analysis of the mandibular movement, Part 2, Mandibular rest position and intercuspal position. *J. of Okayama Dent. Assoc.*, Vol. 2, No. 1, pp 57-66, 1983.
- Unknown. *The Glossary of Prosthodontic Terms, Sixth Edition* *J Prosth Dent*, 1994 Jan, p.59

ADDENDUM I

SCIENTIFIC STUDIES SUPPORTING SAFETY AND THE **EFFICACY OF SURFACE ELECTROMYOGRAPHY IN** **DENTISTRY**

By

Myotronics-Noromed, Inc.

NOVEMBER, 1995

INTRODUCTION TO SURFACE ELECTROMYOGRAPHY FOR MUSCLE

MONITORING OF MASTICATORY MUSCLES

EMG AND ACTION POTENTIALS

The conductive properties of the whole nerve and muscle allow measurement of electrical activity with extra-cellular (surface) electrodes. Typical monitoring sites for masticatory muscles include the masseter, anterior temporalis, posterior temporalis, and digastric suprahyoid muscles. These electrodes do not penetrate the cell membrane, but detect potential differences external to the muscle fiber and distant from the potential source. In the whole muscle or nerve, local current flow is not limited to the membrane surface but will spread throughout the surrounding tissue. A field of current spreads through the extracellular space from the depolarizing membrane.

There is no external current flow and therefore no potential difference is recorded between the two poles of the bipolar electrode until a cellular action potential is initiated. As depolarization initiated by a neural action potential proceeds along the muscle fiber, the outward flow of current through adjacent regions to the membrane makes the recording electrode more positive with respect to the reference electrode.

Action potentials propagating down the nerve are the means by which the central nervous system potentiates contraction of muscle fibers. When the neural action potential crosses the motor end plate the subsequent potentiation of muscle cell electrical discharge creates a current that has a higher potential relative to the reference electrode. As the action potential moves further along the muscle fiber, the recording EMG electrode ceases to be affected by the current flow and the action potential returns to the original baseline.

SURFACE ELECTROMYOGRAPHY

Surface electromyography has long been the “gold standard” for monitoring muscle activity of masticatory muscle at REST and in FUNCTION. The value of surface EMG is best expressed by C.J. DeLuca, Professor of Biomedical Engineering and Research and Professor of Neurology at Boston University, “Surface EMG utilizes sensing electrodes placed on the skin, which allows the clinician to directly and accurately monitor muscle activity. This is far more accurate procedure than conventional manual palpation or touch which can provide only gross assessments of muscle activity.” 1988. W.D. McCall also states “...there is general agreement among both clinicians and investigators that masticatory muscle activity is increased in symptomatic patients as compared with normal subjects. Electromyography is the principal tool used to investigate such differences.” (The Musculature. A Textbook of Occlusion, Quintessence, 1988).

Milner-Brown and Stein, 1975; Moller, 1975; Pruim et al., 1978; Bakke and Moller, 1980; Sheikholeslam et al., 1980; Panteleo et al., 1983; Sheikholeslam and Riise, 1983; Cooper and Rabuzzi, 1984; McDonald and Hannam, 1984; Riise et al, 1984; Riise and Sheikholeslam, 1984; Ahlgren, 1985; Kydd et al., 1986; Balciunas et al., 1987; Wood, 1987; Michler et al., 1988; Chong-Shan, 1989; Chong-Shan and Hui-yun, 1989; Humsi et al., 1989; Christensen, 1989; Mongini et al., 1989; Neill et al., 1989; Jankelson, 1990; Van Eijden et al., 1990; Bakke and Michler, 1991; Koole et al, 1991; Lynn and Mazzocco, 1991; Naeije and Hansson, 1991; Choi, 1992; Dean et al., 1992; Kroon and Naeije, 1992; Visser, et al., 1992; Hickman et al, 1993)

Following are abstracts of studies verifying the use, safety, and efficacy of Electromyography to monitor masticatory muscle function/dysfunction.

1. **Ahlgren, J., Sonesson, B., and Blitz, M. An electromyographic analysis of the temporalis function of normal occlusion. Am. J. of Orthod. Vol. 87, No, 3, March 1985.**

Electromyographic (EMG) activity was recorded from the anterior, middle and posterior regions of the temporalis muscles using bipolar intramuscular electrodes in ten subjects with normal occlusion of the teeth and with the mandible at rest and during clenching. The study showed that the EMG recordings could be well controlled and reproducible and that the error of the method was small in comparison with the individual variations. The study confirmed earlier reports of a close correlation between EMG activity and tension during isometric contraction.

Note: This is one of the early studies to suggest a linear correlation between EMG/motor unit recruitment and bite force.

2. **Bakke, M., and Moller, E. Distortion of maximal elevator activity by unilateral premature tooth contact. *Scand. J. Dent. Res.* 80:67-75, 1980.**

In four subjects the electrical activity in the anterior and posterior temporal and masseter muscles during maximal bite was recorded bilaterally with and without premature unilateral contact. Unilateral premature contact caused a significant asymmetry of motor recruitment in all muscles under study. The mean EMG voltage decreased proportionate to thickness of the overlay introduced as a prematurity. The authors conclude the significant findings were 1, asymmetry of muscle activity with strongest activity on the side of premature contact and, with this asymmetry maintained, 2) a reduction of mean voltage on both sides with increasing height of the overlay.

Note: This is supportive of EMG as a functional indicator of proprioceptive influence of occlusal contact on muscle motor unit recruitment.

3. **Bakke, M. and Michler, L. Temporalis and masseter muscle activity in patients with anterior open bite and craniomandibular disorders. *Scand. J. Dent. Res.* 99:219-228, 1991.**

Facial morphology of 22 patients with anterior open bite and craniomandibular dysfunction were studied. Electromyographic activity was recorded by surface EMG after primary treatment with a reflex release stabilizing occlusal appliance. Maximal voluntary contraction was reduced compared to reference values particularly in patients with muscle dysfunction. Muscle activity increased significantly during maximal bite using the stabilizing appliance. Maximal voluntary contraction was positively correlated to molar contact and negatively to anterior face height, mandibular inclination, vertical jaw relation and gonial angle. The authors concluded that subjects with little occlusal stability and muscle activity would benefit from an increase of tooth contact to utilize their full elevator muscle capacity and increase strength, thereby reducing the risk of muscular strain and overload.

Note: These findings support the EMG function protocol to assess occlusal stability and muscle response to a specific occlusal position and contact.

4. **Balciunas, B.A., Staling, L.M. and Parente, F.L. Quantitative electromyographic response to therapy for myo-oral facial pain: A pilot study. *J. of Prosth. Dent.* Vol. 58 No.3, Sept. 1987.**

Five subjects with common symptoms of TMD were studied using integrated EMG of the anterior temporalis and masseter muscles. The authors conclude that “Our results agree with those of other investigators who demonstrate a positive contribution by masticatory EMG data to confirm and quantify objectively the subjective symptoms.”

Note: The authors note in conclusion that “the occlusal position of clenching was the jaw position that provided the most definitive information.” This is supportive of the maximal clench clinical protocol.

5. **Bigland, B., and Lippold O.C.J. The relation between force, velocity and integrated electrical activity in human muscles. *J. of Physiol.* 123:214-224, 1954.**

The authors compared needle and surface electrodes under isometric conditions. Good correlation was obtained. The authors conclude that tension, velocity and electrical activity are interdependent and the integration of EMG signals provides a composite measure of the number of active fibers and their frequency of excitation.

Note: This early study supports the validity of the EMG signal as a reliable indicator of muscle motor unit function.

6. **Burdette, B.H. and Gale, E.N. Reliability of surface electromyography of the masseteric and anterior temporal areas. *Arch Oral Biol.* Vol. 35 9:747-751, 1990.**

Bipolar surface EMG electrodes were used to record tonic resting EMG activity of the anterior temporalis and masseter muscles for 2 consecutive sessions in thirty seven patients suffering from MPD. The authors suggest that the reliability of tonic postural EMG data recorded from the masseteric area is satisfactory when recording conditions are standardized. Smaller coefficient correlation of anterior temporal postural activity was noted and possibly attributable to the dynamic role of this muscle in maintaining postural rest position of the mandible.

7. **Burdette, B.H., and Gale, E.N. Intersession Reliability of surface electromyography. J. of Dent. Res., Abstr. No. 1370, Volume 66, 1987.**

The purpose of this experiment was to compare EMG data from trials both within the same session without moving the electrodes and between sessions two weeks apart. Using the standardization techniques described, repeatability of surface EMG data between recording sessions was considered satisfactory for the masseter muscles.

8. **Burdette, B.H., and Gale, E.N. The effects of treatment on masticatory muscle activity and mandibular posture in myofascial pain-dysfunction patients. J. Dent. Res. 67 (8) : 1126-1130, Avevst 1988.**

Forty one TMJ) patients were evaluated with surface EMG to measure anterior temporalis and masseter postural EMG activity. Twenty three asymptomatic subjects were tested as controls. The pre-treatment EMG values of both the masseteric and anterior temporalis muscles were significantly higher for the pain group than the control group. These result suggest that tonic masticatory muscle activity may be elevated in MPD patients. They also suggest that a decrease in EMG activity in the masseter and anterior temporalis muscles and an opening of the postural rest position of the mandible may accompany completion of psychophysiological therapy, but these changes do not correspond directly with the outcome of that therapy.

Note: This study confirms many others that suggest elevated postural EMG activity is a consistent finding in patients suffering from TMD.

9. **Carlson, C.R., Okeson, J.P., Falace, D.A., Nitz, A.J., and Anderson, D. Stretch based relaxation and the reduction of EMG activity among masticatory muscle pain patients. J. Craniomandib. Disord Facial Oral Pain 5:205-212, 1991.**

This study of 34 patients with myogenous pain with no arthrogenous pain used bipolar EMG surface electrodes to study response to relaxation procedures. The authors conclude that the study of EMG activity after relaxation is a useful research tool to understand mechanisms of muscle pain disorders.

10. **Chaconas, S.J., and Fragiskos, F.D. Vertical dysplasias and myofascial pain dysfunction syndrome. Compend Contin Educ Dent. Vol. XI, No. 7, 1990.**

The authors present a clinical case study of a patient who had sought relief from MPD symptoms from multiple practitioners. Electromyography was used to identify masticatory muscle spasm and to assist establishing a therapeutic occlusal position. The patient's symptoms completely resolved after placement of an appliance in a neuromuscularly coordinated position.

11. **Choi, J. A study on the effects of maximal voluntary clenching on the tooth contact points and masticatory muscle activities in patients with temporomandibular disorders. J. Craniomand Disord Facial Oral Pain 6:41-46, 1992.**

This study was conducted to evaluate the occlusal contact stability at the moment of dynamic occlusal tooth contacts and to investigate the correlations between the occlusal contact stability and masticatory muscle activity during maximal voluntary clenching in twenty TMD patients. The authors concluded the muscular disharmony of the anterior temporal muscles of the patient group was significantly greater than that of the control group. Masseter muscle disharmony was not significantly greater than the control group. TMD patients demonstrated less symmetrical and simultaneous tooth contact resulting in asymmetrical anterior temporalis activity during maximal clench. There was a significant improvement in muscle synergy after one week of occlusal splint use in the patient group.

Note: Correlation of occlusal stability and Muscle EMG symmetry supports EMO maximal clench protocol.

12. **Chong-Shan, S. Proportionality of mean voltage of masseter muscle maximum bite force applied to diagnosing temporomandibular joint disturbance syndrome. J. Prosthet Dent 62:682-684, 1989.**

Maximum bite force in the molar area and the corresponding mean EMG value of the corresponding masseter in 29 patients and 27 controls were recorded. In contrast to the controls, the maximum bite force of the patients was smaller, the mean voltage was nearly equal and the proportionality of the mean voltage to the maximum bite force of the patients was greater. These results indicate that the masticatory muscles of patients with temporomandibular joint dysfunction are in a state of hyperactivity and tension.

13. **Chong-Shan, S., and Hui-yun, W. Postural and maximum activity in elevators during mandible pre- and post-occlusal split treatment of temporomandibular joint disturbance syndrome. J. Oral Rehabil. Vol. 16:155-161, 1989.**

“Electromyograms of the temporal and masseter muscles in sixty patients with temporomandibular joint disturbance syndrome and thirty controls were recorded and integrated on-line in the postural position and during maximum clenching, before and after splint therapy. Contrasting with the controls, the myoelectric activity of the patients was higher in the postural position and lower during maximal clenching, whilst the former in percentage terms increased when compared to the later...The results show that the mandibular elevators in the patients with TMJDS were hyperactive and tense, and that the occlusal splint was useful for treating such dysfunction.”

Note: This well controlled study supports the clinical protocol for both posture and function EMG studies of TMD patients.

14. **Chong-Shan, S., and Hui-yun, W. Value of EMG analysis of mandibular elevators in open-close-clench cycle to diagnosing TMJ disturbance syndrome. J. Oral Rehabil. Vol. 16:101-107, 1989.**

The EMG's of the temporal and masseter muscles in 60 TMD patients and 30 controls were recorded during rhythmical open-close-clench movement before and after occlusal splint therapy. The author concluded that the duration of muscle contraction before initial tooth contact was significantly different in subjects and controls, and it is a useful modality in diagnosis of muscular dysfunction.

15. **Clark, G.T., Beemsterboer, P.L., Solberg, W.K., and Rugh, J.D. Nocturnal electromyographic evaluation of myofascial pain dysfunction in patients undergoing occlusal splint therapy. J. Am. Dent. Assoc. Vol. 99:607-611, 1979.**

The level of nocturnal masseter muscle activity in 25 MPD patients was monitored with surface EMG before, during and after therapy with occlusal splints. Correlations were made between the severity of symptoms before treatment and the effectiveness of the splint in reducing nocturnal activity of muscle.

16. **Clark, O.T., Beemsterboer, P.L., and Rugh, J.D. Nocturnal masseter muscle activity and the symptoms of masticatory dysfunction. J. Oral Rehabil. 8:279-286, 1981.**

“The results presented in this study support the hypothesis that prolonged jaw closing muscle hyperactivity is correlated with the symptoms of jaw dysfunction. More specifically, the greater the level of nocturnal EMG a subject had the more likely he was to have signs and symptoms of jaw dysfunction.

17. **Christensen, L.V. Reliability of maximum static work efforts by the human masseter muscle. Am. J. Orthod. Dentofac. Orthop. 95:42-45, 1989.**

Six healthy subjects clenching in centric occlusion were studied for reliability of nonfatiguing maximum voluntary static work effort. Maximum voluntary teeth clenching was performed for 10 seconds on 2 different days, each with two trials, and maximum static work efforts quantified by integrated surface EMG. Reliability was determined by factorial analysis of variance and intraclass correlations. Data reduction showed that maximal voluntary static work efforts were reproduced reliably during the four different trials.

Note: This study supports the reliability of the EMG maximal clench protocol. The author also adds that the most ideal method would be to take EMG records before and after treatment protocols within a day. This is consistent with the intra-patient data clinical protocol routinely used.

18. **Cooper, B.C., and Rabuzzi, D.D. Myofascial pain dysfunction syndrome: a clinical study of asymptomatic subjects. Laryngoscope, Vol. 94, No.1, p 68-75, Jan 1984.**

A study of 26 asymptomatic subjects using EMG to evaluate occlusal and muscle function revealed the presence of subclinical muscle asymmetry and dysfunction in a significant number of patients. The author concludes that measuring mandibular movement and muscle function with EMG is a valuable adjunct to subjective history records.

19. **Cooper, B.C., Cooper, D.D., and Lucente, F.E. Electromyography of masticatory muscles in craniomandibular disorders. *Laryngoscope*, Vol. 101:150-157, Feb 1991.**

Electromyographic recording using surface electrodes were made bilaterally on the masseter, anterior temporalis and digastric muscles in 641 craniomandibular dysfunction patients, before and after transcutaneous electrical neural stimulation, at their initial presentation and following insertion of a mandibular appliance. The TENS therapy significantly decreased muscle hyperactivity. The use of a neuromuscularly balanced appliance resulted in significant reduction of symptoms, reduction of resting EMG activity, Increase in muscle activity in maximum effort and improved coordination of muscle groups during mandibular movement. The authors conclude “Electromyography of certain masticatory muscles is a clinically useful method of quantifying musculoskeletal dysfunction in patients with clinically diagnosed craniomandibular disorders...The use of electromyography is paramount in documenting increased and more symmetrical clenching force following creation of a neuromuscularly based occlusal or biting position.”

20. **Cram, J.R., and Klemons, T.M. EMG: Comparisons in craniofacial muscles following therapy for head and neck pain. *Med. Electr.* pp 106-110, Dec. 1988.**

The anterior and posterior temporalis, masseter, and digastric muscles of thirty consecutive patients diagnosed as having headaches due to MPD were monitored with surface EMG pre- and post- treatment. All patients reported improvement in head pain. There was a statistically significant correlation between reduction of symptoms and reduction of EMG activity in 25 of the 29 patients. The authors conclude “It appears that the bioelectric activity measured by the computerized EMG may be an effective indicator of the efficacy of treatment amongst patients experiencing head pain of musculoskeletal origin.

21. **Cram, J.R., and Engstrom, D. Patterns of neuromuscular activity in pain and nonpain patients. *Clin Biofeed and Health* Vol. 9, No.2, p 106-115, 1986.**

This study compared the patterns of surface EMG activity in normal subjects and in patients with history of chronic pain. Surface EMG activity was sampled from the right and left homologous sites of ten muscle groups in sitting and standing posture. Statistical comparisons between the normal subjects (N=104) and chronic pain patients (N=200) were conducted on each of 40 samples of surface EMG. The results of the study indicate that chronic pain patients exhibit a higher level of surface EMG activity. These findings support previous research indicating abnormal neuromuscular activity and posture in chronic pain patients.

22. **Dean, J.S., Throckmorton, G.S., Ellis, E. and Sinn, D.P. A preliminary study of maximum voluntary bite force and jaw muscle efficiency in pre-orthognathic surgery patients. *J. Oral Maxillofac Surg.* 50:1284-1288, 1992.**

This study compared the ability to generate occlusal force for 84 patients requiring orthognathic surgery for facial deformities and 57 controls. Maximal and submaximal bite forces were measured at the incisor and first molar bit positions. Electromyographic activity was recorded bilaterally from the anterior temporalis, posterior temporalis, and masseter muscles during each bite. An efficiency ratio was calculated for the jaw muscles by dividing the level of EMG by the occlusal force. There was a reduced ability to generate occlusal forces in the patients before surgery. The reduction in maximal occlusal force was correlated with reduced efficiency of the jaw muscles.

23. **Erlandson, P.M. and Poppen, R. Electromyographic biofeedback and rest position training of masticatory muscles in myofascial pain-dysfunction patients. *J. Prosthet Dent.* 62:335-338, 1998.**

Twenty four women patients with myofacial pain dysfunction were divided into three groups of eight. All received bilateral masseter EMG biofeedback training. One group received biofeedback only; one group received additional instructions to place their jaw in rest position using EMG; and one group was treated with a prosthetic appliance. The instruction and prosthesis groups obtained significantly greater electromyographic reductions in masseter activity and increases in ROM compared to the biofeedback only group. Subjects with pain obtained a significant reduction in pain. The authors conclude “Two procedures that directly placed the jaw in a relaxed or rest posture resulted in decreased masticatory muscle activity in MPD patients. This decreased activity supports previously reported findings.”

24. **Gervais, R.O., Fitzsimmons, G.W., and Thomas, N.R. Masseter and temporalis electromyographic activity in asymptomatic, subclinical, and temporomandibular joint dysfunction patients. J. Craniomand Pract. Vol.7, No. 1, p 52-57, Jan. 1989.**

Resting EMG levels for each masseter and temporalis were obtained from three groups of subjects: asymptomatic (N=24); subclinical (N=31) and symptomatic patient (N=61). The patient group demonstrated significantly higher EMG activity than the asymptomatic or subclinical groups for all variables except the right masseter. The temporalis was found to be the site of greatest EMG activity more frequently than the masseter. These findings strengthen diagnostic and assessment procedures and criteria, as well as suggest alternate treatment and research protocols.

Note: This is one of many recent studies statistically confirming a significant difference in resting activity in symptomatic and asymptomatic patients.

25. **Goldensohn, E.S. Electromyography from Disorders, of the Temporomandibular Joint. Schwartz, L., ed. W.B.Saunders, Philadelphia, Jan 1966.**

The author emphasizes that surface electrodes are the electrodes of choice for temporomandibular dysfunction studies. The EMG studies showed a significant difference in EMG activity at rest, during function and during clenching between patients complaining of facial pain and dysfunction versus asymptomatic patients.

26. **Helkimo, E., Carlsson, G.E., and Carmeli, Y. Bite force in patients with functional disturbances of the masticatory system. J. Oral Rehab. Vol. 2:397-406, 1975.**

In thirty patients treated because of dysfunction and thirty six control subjects bite force was registered before, during and after treatment. Repeated tests of bite force in the control group gave identical results. Bite force in the patient group was lower than the control group but increased with palliation of the symptoms during treatment.

Note: The finding of significant difference between bite force in patient and control groups is supplemental to the rationale for the EMG function test since integrated EMG and bite force are linear.

27. **Hermens, H.J., Boon, K.L., and Zilvold, G. The clinical use of surface EMG. Medica Physica. 9:119-130, 1986.**

The use of surface EMG as a tool for quantification is described. The specific advantages of surface EMG for evaluating functions of the neuromuscular system are discussed. The authors conclude “that surface EMG can certainly lead to a reproducible method of quantification.”

“It is possible to indicate a range of normal values to discern pathology. It is also possible to measure changes in parameters during a follow-up investigation.”

28. **Hickman, D.M., Cramer, R., and Stauber, W.T. The effect of four jaw relations on electromyographic activity in human masticatory muscles. Archives of Oral Biol. Vol. 38, No. 3, pp 261-264, 1993.**

This study of 20 asymptomatic subjects used surface EMG of the anterior temporalis and masseter muscles to evaluate masticatory muscle function at positions determined by the leaf gauge (LG), manually manipulated (CR) and neuromuscular (NM) bite during maximal static clench. The leaf gauge position consistently demonstrated the lowest EMG activity, while the neuromuscular position displayed the highest degree of muscle activity. Similarly, the ratio of the masseter/temporalis EMG activity during maximal clench was lower for the leaf gauge and centric relation positions and highest for the neuromuscular position. These data indicate that the neuromuscular position produced the greatest total muscle recruitment, with more masseter involvement during clenching, and enabled the subjects to generate greater biting forces in the neuromuscular position compared to the leaf gauge and centric relation position.

29. **Humsi, A.N.K., Naeije, M., Hippe, J.A., and Hansson, T.L. The immediate effects of a stabilization splint on the muscular symmetry in the masseter and anterior temporal muscles of patients with craniomandibular disorder. J. Prosthet Dent. 62:339-343, 1989.**

“In 36 myogenous craniomandibular disorder patients, the immediate effects of a stabilization splint on the symmetry in the activities of the masseter and anterior temporal muscles during submaximal clench were investigated electromyographically. The immediate changes in masseter muscle activity suggest that muscular symmetry is an objective tool in the evaluation of the treatment provided.”

30. **Ingervall, B., and Carlsson, G.E. Masticatory muscle activity before and after elimination of balancing side occlusal interference. J. Oral Rehabil Vol. 9:183- 192, 1982.**

The activity of the masseter and anterior and posterior temporal muscles was studied by electromyography (EMG) in thirteen subjects with unilateral balancing side interferences and in twelve control subjects without such interferences. In both groups the EMG recordings were made during postural activity and various functions of the masticatory system and in the interference group they were repeated twice after occlusal adjustment. The findings of this study were inconclusive regarding the influence of balancing interferences in a young adult population but the authors conclude “It is obvious from the present results that there is a relationship between occlusal factors and muscle activity in mandibular posture and during functions such as chewing and swallowing.”

31. **Jankelson, R.R. Analysis of maximal electromyographic activity of the masseter and anterior temporalis muscles in myocentric and habitual centric in temporomandibular joint and musculoskeletal dysfunction. Pathophysiology of Head and Neck Musculoskeletal Disorders. Bergimini M (ed), Front Oral Physiol. Basel, Karger, 7:83-98, 1990.**

Analysis of 46 TMD patients showed masseter EMG activity significantly lower than anterior temporalis EMG activity during maximal bite to habitual occlusion. This study supports previous studies showing reduced EMG activity during maximal bite in TMJ patients. There was a positive correlation between reduced patient symptoms and increased maximal EMG activity. The author concludes that integrated EMG of maximal clench appears to be a reliable quantitative modality to identify functional disorders of the masticatory system. The use of maximal effort EMG is a reliable quantitative indicator of pre- and post- treatment masticatory function.

32. **Jankelson, R.R. Validity of surface electromyography as the “gold standard” for measuring muscle postural tonicity in TMD) patients. Anthology of Craniomandibular Orthopedics Vol. II, ed. Coy, R. pp. 103-125, 1992.**

The author presents a comprehensive scientific literature review examining the validity of surface EMG to study postural activity of craniomandibular muscles. After examination and critique of biologic electrochemical models the author concludes that manual palpation is not a reliable indicator of histochemical/ electrical status of muscle and that EMG is well established in the literature as the “gold standard” for measure postural muscle tonicity. Lowering of postural activity of hypertonic muscle is a universal therapeutic objective and surface EMG is a reliable indicator of muscle in the resting state.

33. **Jarabak, J.R. An electromyographic analysis of muscular and temporomandibular joint disturbances due to imbalances in occlusion. Angle Orthodont. (26)3:170-190, 1956.**

In a study of twenty two patients EMG records of neuromuscular activity from the temporal muscles was analyzed during biting, rest after biting and rest after speaking. The author concluded: “1. The behavior of skeletal muscle is a faithful index of the state of the motor nerve center (lower motor neuron). 2. Temporal muscle spasms occur simultaneously with functional disturbances in the temporomandibular joint. 3. Functional disturbances in the temporomandibular joint may have their etiology in occlusal interferences of the teeth. 4. Muscle spasms disappear in the temporal muscles when occlusal interferences were removed. Upon removal of the splint, muscle spasms reoccurred.”

34. **Keefe, F.J. and Dolan, E.A. Correlation of pain behavior and muscle activity in patients with myofascial pain-dysfunction syndrome. J Craniomandib Disord Facial Oral Pain 2:181-184, 1984.**

The authors studied 31 patients diagnosed as having MPD in order to examine the degree to which overt pain behavior relates to muscle tension in MPD patients. Monitoring masseter muscle activity with surface EMG the authors concluded; “This study found a significant relationship between overt pain behavior and muscle tension in MPD patients.”

35. **Konchak, P.A., Thomas, N.R., Lanigan, D.T. and Devon, R.M. Freeway space measurement using mandibular kinesiograph and EMG before and after TENS. Angle Orthodont. p 343-350, Oct 1988.**

This study expands on a previous pilot study of the efficacy of TENS to assist in determination of the resting position of the mandible. Surface EMO of the masseter and anterior temporalis to quantify muscle activity before and after application of TENS.

36. **Koole, P., deJongh, H.J., and Boering, G. A comparative study of electromyograms of the masseter, temporalis, and anterior digastric muscles obtained by surface and intramuscular electrodes: Raw EMG. J Craniomand Pract Vol. 9, No. 3:228-240 July 1991.**

Electromyographic activity was synchronously recorded by surface and intramuscular needle electrodes in the same muscle. The activity of the masseter, temporalis and anterior digastric was studied. The authors concluded “The use of surface and intramuscular electrodes in cyclic jaw movements gives comparable results with respect to the onset and offset of activity of the muscles of mastication.”

37. **Kroon, G.W., and Naeije, M. Electromyographic evidence of local muscle fatigue in a subgroup of patients with myogenous craniomandibular disorders. Arch Oral Biol. Vol. 37, 3:215-218, 1992.**

Ten patients with myogenous craniomandibular disorders and ten controls were studied using surface EMG monitoring of the masseter and anterior temporalis muscles. The authors concluded: “The results for the maximum voluntary bite force and for the 50% isometric endurance time were indicative of masticatory muscle weakness in the patients with craniomandibular disorder. The maximum voluntary bite force was significantly lower in patients than controls. The endurance times were the same for the two groups despite the lower bite forces sustained by the patients. These results were confirmed by the characteristics of the electromyograms.”

38. **Kydd, W.L., Choy, E., and Daly, C. Progressive jaw muscle fatigue and electromyogram activity produced by isometric unilateral biting. J. Craniomand Pract. Vol. 4, 1:18-21, 1986.**

The purpose of this study using 30 subjects was to quantify the duration of force required during unilateral biting to produce the onset of subjective fatigue and pain in the masseter and anterior temporalis muscles of healthy adult females. “In the subjects with contralateral pain discomfort, EMG evaluation demonstrated that integrated EMG activity on the nonstressed contralateral side was twice that of the ipsilateral side where the force was applied.” This study confirms many others that correlate pain, bite force and EMG activity.

39. **Lippold, O.C.T. The relation between integrated action potentials in a human muscle and its isometric tension. J. Physiol. 117:492-499, 1952.**

EMG action potentials were recorded from calf muscles of thirty subjects at ten different strengths of contraction.

The study found that in all thirty patients the relation between the isometric tension of a voluntarily contracting human muscle and its integrated electromyogram is always directly linear.

Note: This classic study confirms the basis for an integrated EMG/motor unit recruitment correlation that is the basis of the maximal clench isometric function test.

40. **Lloyd, A. Surface electromyography during sustained isometric contractions. J. Appl. Physiol. 305:713-719, 1971.**

Ten subjects were asked to maintain isometric contractions of the elbow flexor muscles as long as possible at 50% and 70% of maximum voluntary strength and to report when they experienced five successive levels of pain resulting from the contraction. Surface EMG recordings were made on the biceps muscle and three peripheral muscles. EMG frequency analysis demonstrated that during sustained contraction amplitude resulted from an increase in the activity within a narrow frequency band. The authors conclude: “The results of the present experiment suggested that with an increase in the duration of a constant force, synchronization and recruitment produced a increase in the amplitude of the surface EMG. Surface EMG recordings during strenuous work endurance seemed to provide considerable information about muscle activity.”

41. **Lous, I., Sheikholeslam, A., and Moller, E. Postural activity in subjects with functional disorders of the chewing apparatus. Scand. J. Dent. Res. 78:404- 410, 1970. See Abstract on page 43.**

42. **Lynn, J.M. Craniofacial neuromuscular dysfunction vs. function: A comparison study of the condylar position and intro-articular space. Pathophysiology of Head and Neck Musculoskeletal Disorders. Bergamini M (ed) Front Oral Physiol. Basel, Karger Vol. 7, p 136-143, 1990.**

This study of 100 patients (200 joints) with signs and symptoms of TMD) were monitored and measured for condylar position change comparing habitual position with a TENS/EMG/CMS generated position. The author concludes that there is no standard normal joint space in neuromuscular dysfunction patients. However, the use of EMG to generate a rest position of the mandible resulted improvements in resting and functional EMG activity that correlated with the reduction in symptoms.

43. **Lynn, J.M. and Mazzocco, M. Intraoral splint therapy: muscles objectively. Funct Orthodont. p 11-27 Nov/Dec 1991.**

This study of 203 consecutive TMD patients used EMG data from four paired muscle groups to help establish a therapeutic position for an occlusal appliance. EMG values were recorded at rest and during function before and after appliance therapy. All resting measures showed a significant decrease in EMG activity while function increased significantly 12 weeks after treatment. The study found significant correlation between reduction of pain and lowered EMG resting levels and increased maximal function activity.

Note: This study with a large patient sample statistically establishes significant longitudinal intra-patient EMG parameters and subjective pain history.

44. **Lynn, J.M., Mazzocco, M.W., Miloser, S.J., and Zullo, T. Diagnosis and treatment of craniocervical pain and headache based on neuromuscular parameters. Am J Pain Management. Vol.2, No.3 July 1992.**

There is increasing evidence supporting the premise that hypertonicity within facial muscles is an etiologic factor for some chronic headache patients. This muscular hypertonicity is the result of neuromuscular imbalances within the head and neck. Through the analysis of electromyograph (EMG) data, it is possible to construct an intraoral orthosis which creates neuromuscular balance and subsequently relieves the pain.

This study attempted to identify the relationship of EMG-measure neuromuscular dysfunction to reported craniocervical pain and the effectiveness of EMG-based orthoses on reversing myospastic conditions. Results of the study indicate a significant decrease in muscle spasm at rest and a significant increase in muscular activity during function following treatment with EMG based appliances. Craniocervical pain reduction correlated to the decrease in resting EMG and increase in function EMG activity. The authors conclude that utilization of electromyography is a valuable tool during the assessment and treatment of chronic facial pain patients.

45. **MacDonald, J.W.C., and Hannam, A.G. Relationship between occlusal contacts and jaw-closing muscle activity during tooth clenching: Part I. J. Prosth. Dent. Vol. 52, No. 5:718-729 Nov 1984.**

In 10 subjects surface EMG was recorded from the masseter and temporalis muscles during vertical clenching and eccentric clenching. The authors conclude “The findings on this electromyographic study on changes of the contact points, size of contact point, and the direction of effort applied on a contact point confirm their specific association with the activity of muscle groups.”

46. **Mann, A., Zuazola, R.V., Sirhan, R., Quiroz, M., and Rocabado, M. Relationship between the tonic elevator mandibular activity and the vertical dimension during the states of vigilance and hypnosis. J Craniomand Pract Vol.8, No. 2:163-170 April 1990.**

The variation of the masseter and anterior temporalis postural EMG activity during vigilance and after hypnosis was studied and referenced to vertical dimension. Under hypnosis a significant reduction of postural EMG activity was observed together with an significant increase of interocclusal space. The authors conclude that hypnosis is a good technique to produce effective neuromuscular relaxation of mandibular muscles and may be effective in reducing spasm of TMD patients.

47. **Manns, A., Miralles, R., and Cumsille, F. Influence of vertical dimension on masseter muscle electromyographic activity in patients with mandibular dysfunction. J. Prosth Dent Vol. 53, No. 2:243-247, Feb. 1985.**

This study of 61 TMD patients analyzed the EMG response to occlusal splints adjusted to different vertical dimensions. The authors conclude: This study suggests that an increase in vertical dimension of occlusion to or near the vertical dimension of least EMG activity by means of occlusal splints can be an effective way to obtain a reduction in masseteric muscle activity.”

48. **Michler, L., Bakke, M., Andreassen, S., and Hennington, E. On-line analysis of natural activity in muscles of mastication. J. Craniomand Disord: Facial and Oral Pain 2:65-82, 1988.**

The authors present an EMG on-line analysis to record muscle activity during mastication. They conclude that the computerizing of the EMG protocol is a significant addition to quantitative methods of whole-muscle EMG routinely used clinically and experimentally the past 20 years. The function EMG protocol provides “Instant presentation of results during treatment represents a valuable check of procedures to improve occlusal stability as judged by the patient’s nervous system in keeping with correlations between muscle activity and stability.”

49. **Milner-Brown, H.S., and Stein, R.B. The relation between the surface electromyogram and muscular force. J. Physiol. 246:549-569, 1975.**

A linear relation between electrical activity and tension during constant or zero velocity change in muscle length was demonstrated using both needle and surface EMG. This study validates the rationale for clinical EMG protocol using isometric maximal bite. The EMG function test quantifies motor unit recruitment at a given mandibular position. This study demonstrated that as the electrical activity increases, the proportion of overlap between potentials arising in different parts of the muscle remains constant, The excitation is related to the number and discharge frequency of active units,

50. **Miralles, R., Zuniga, C., Santander, H., and Maimis, A. Influence of mucosal mechanoreceptors on anterior temporalis EMG activity in patients with craniomandibular dysfunction: a preliminary study. J. Craniomand. Pract. Vol. 10 No.1:21-27, Jan 1992.**

Bilateral surface EMG electrodes placed on the anterior temporalis muscles were used in this study to evaluate postural (tonic) EMG activity in 15 patients with craniomandibular dysfunction. There was not significant differences in EMG activity before and after the use of a palatal base appliance.

51. **Miralles, R., Mendoza, C., Santander, H. and Zuniga, C. Influence of stabilization occlusal splints on sternocleidomastoid and masseter electromyographic activity. J. Craniomand. Pract. Vol. 10 No.4:297-304, Oct 1992.**

Bipolar surface EMG recordings of the masseter and sternocleidomastoid muscles on 14 symptomatic subjects were monitored to analyze the effect of a occlusal appliance on muscle activity. Postural (tonic) EMG activity, as well as during swallowing and maximal voluntary clenching, was recorded with and without a stabilization occlusal appliance. These parameters were monitored with and without the occlusal appliance. During swallowing the activity of both muscles was significantly lower with the appliance, suggesting possible efficacy of the appliance to reduce muscle tenderness.

52. **Mitani, H. and Yamashita, Y. et al. On the Power spectra of the surface electromyograms of masticatory muscles. J. Osaka Dent Univ. Vol. 6, No. 1, 1972.**

The surface EMG of the bilateral middle masseter and anterior and posterior temporalis of three subjects with normal occlusion was recorded, analyzed and a power spectrum obtained. This study of the power spectra of surface electromyograms of masticatory muscles helped define the technical and physical parameters for the present clinical EMG.

53. **Molin, C. Vertical isometric muscle forces of the mandible: A comparative study of subjects with and without manifest mandibular pain dysfunction syndrome. Acta Odont Scand. 30:485-499, 1972.**

This study of 31 female subjects with TMD and 30 healthy control subjects compared isometric bite forces at maximal and submaximal levels. The conclusion was that the symptomatic subjects could produce only one-half to two-thirds the bite forces produced by the control group. The linearity between bite force and integrated EMG support diminished maximal bite EMG activity in the symptomatic patient.

54. **Moller, E. Clinical electromyography in dentistry. Acta Odont Scand. Vol. 19, 2:250-266, 1975.**

The author concludes that surface electrodes are applicable to study the action of the temporalis, masseter and other facial muscles. Other conclusions state “Electromyography of the activity during full effort is an important supplement to the clinical examination of the muscles of mastication.... Electromyography provides an objective means of deciding the degree of predominance of one side during natural chewing...As a supplement to the clinical and radiological investigation, electromyography can contribute to a more precise diagnosis of functional disorders of the chewing apparatus and of the importance of function in malocclusion.”

55. **Moller, E. The chewing apparatus: An electromyographic study of the action of the muscles of mastication and its correlation to facial morphology. Acta Physiol Scand Vol. 69, Supp 280 2:73-75, 1975.**

A controlled study of 36 healthy subjects monitoring anterior temporalis, posterior temporalis and masseter muscle activity investigating maximal EMG activity when the subjects clenched in the intercuspal position. Values for electromyographic data and facial morphology using logarithmic transformation was established.

56. **Moller, E., Sheikholeslam, A., and Lous, I. Response of elevator activity during mastication to treatment of functional disorders. Scand J. Dent Res 92:64-83, 1984.**

The pattern of elevator muscle activity using bipolar surface EMG of the temporalis and masseter muscles during mastication in 37 patients with pain and dysfunction and 43 control subjects was studied before and after treatment. Compared to controls, patients before treatment chewed with greater percent of maximal elevator activity, with longer relative contraction times and stronger intermediary activity between chewing strokes. These EMG parameters established quantitative profiles of muscle hyperactivity.

The significant difference between patients and controls suggest that there is an increased load put on muscle during mastication due to unstable functional occlusion caused by muscle control beyond the guidance necessary for chewing. The authors further conclude, “Hyperactivity in terms of relatively increased postural activity has also been shown and included all muscles under study, but the most substantial differences concerned the temporal muscles. Hence, the temporal muscles tend to be susceptible to static overload while the masseter muscles are most likely to acquire the symptoms and signs of overload during the strong, dynamic contractions of mastication.”

57. **Moller, E., Sheikholeslam, A., and Lous, I. Deliberate relaxation of the temporal and masseter muscles in subjects with functional disorders of the chewing apparatus. Scand J. Dent Res 79:478-482, 1971.**

This controlled study replicated the results of Lous (1970) using bilateral surface EMO to study the activity of the anterior temporalis and masseter muscles, comparing response of 24 patients with functional disorders of the muscles of mastication and the TMJ with 45 patients without such disorders. The use of Electromyography permits direct observation of muscle relaxation. The authors conclude, “Our findings suggest that hyperactivity in the temporal muscles reflects abnormal posture of the mandible and that the supine position is suitable for inducing relaxation during clinical examination and treatment.”

58. **Mongini, F., Tepia-Valenta, G., and Conserva, E. Habitual mastication in dysfunction: a computer-based analysis. J. Prosthet. Dent. 1:484-494, 1989.**

The different parameters of habitual mastication in stomatognathic dysfunction, mandibular movements and electromyographic activity of elevator muscles were recorded during three chewing sequences in 86 dysfunctional subjects. Bipolar surface EMG electrodes were used in the study. The author concluded, “The EMG data also showed marked alterations with increase of masseter activity during opening in some patients and an irregular and more random distribution during closing. In particular the distinction between a prevalently isotonic and a prevalently isometric muscle contraction pattern observed in the normals during closing was less evident. An index of isometric contraction was calculated for each subject and showed a tendency to reduce or suppress the isometric phase of contraction. This tendency was more marked in the TMJ-impaired patients as opposed to the muscle patients. Indeed, between normal and TMJ impaired patients the discriminative capability of the index was good with few instances of false positive or false negatives.”

59. **Moss, J.P., and Greenfield, B.E. An electromyographic investigation of class III cases. Tr. Br. Study Orthod. p 147-156, 1965.**

A clinical EMG protocol for assessing muscle activity is described. Thirty two patients with Class III malocclusion and forty patients with normal occlusion were compared for differences in electromyographic patterns. Significant difference in these patterns was found. "The electromyographic patterns of 40 Class I cases and 32 Class III cases have been investigated and the activity of the anterior masseter muscle and the posterior temporal muscle have been shown to be important in determining the anteroposterior relationship of the jaws.

A longitudinal study during treatment has shown that following treatment, when the incisors are in a Class I relationship, the jaw may be in a posterior relationship, and further treatment is necessary to eliminate this displacement and possible loosening of the incisors." The authors conclude that this EMG protocol a valid clinical method of assessing the relationship of the jaw before and after treatment.

60. **Moss, J.P. and Chalmers, C.F. An electromyographic investigation of patients with a normal jaw relationship and a class III jaw relationship. Am J Orthod. Vol. 665:538-556, Nov 1974.**

Surface EMG electrodes were determined to be the most suitable to monitor anterior masseter and posterior temporalis muscle activity in four groups of patients; normal adults, normal children, postural Class III and skeletal Class III subjects. The authors concluded, "that recordings of a group of patients with a similar occlusal relationship would look like recordings of the same individual made on separate occasions. Their pattern would be distinct, and the correlation and variance covariance structure would be fixed and quite unlike that due to errors in the method itself. The authors conclude that the ratio of masseter to temporal activity is a suitable discriminator.

61. **Munro, R.R. Electromyography of the masseter and anterior temporalis muscles in patients with atypical facial pain. Australian Dent J. p 131-139, April 1972.**

This study of 26 patients with atypical facial pain used surface electrodes on the masseter and anterior temporalis to study duration of muscle contraction before initial tooth contact and latency and duration of inhibition. When compared to a large control group the duration of muscle contraction and latency in the open-close-clench cycle was significantly longer.

62. **Myslinski, N.R., Buxbaum, J.D., and Parente, F.J. The use of electromyography to quantify muscle pain. Meth and Find Exptl Clin Pharmacol. Vol. 7 10:551-556, 1985.**

This study was designed to determine the validity of using electromyography to quantify muscle pain in patients with chronic MPD. Ten patients with mild to severe pain and no psychologic overlay were studied. Measurement of subjective pain and EMG activity were recorded before and after standard analgesic therapy. Surface EMG recordings were obtained from the masseter and anterior temporalis muscles during rest, swallow, clench and chewing modes of activity. The authors conclude, "In the present study, there was a parallel relationship between objective EMG and perceived pain. It showed that the test for the multiple R was statistically reliable. As the pain attenuated after treatment and then returned, the EMG signals followed accordingly in a graded manner.

63. **Naeije, M., and Hansson, T.L. Short-term effect of the stabilization appliance on masticatory muscle activity in myogenous craniomandibular disorders patients. J. Craniomandib. Disord. Facial Oral Pain. 5:245-250, 1991.**

The short-term effect (4 to 6 weeks) of a stabilization appliance on masticatory muscle activity was investigated in 26 myogenous craniomandibular dysfunction patients. Surface EMG recordings of the anterior temporalis and masseter muscles were made before and immediately after appliance delivery. The average EMG activity of the masseter muscles remained the same during the period of appliance use, whereas the anterior temporalis muscles showed an immediate and long lasting reduction in activity. The appliance also resulted in an improvement in the balance of left and right masseter activity. There was minor improvement in temporal muscle symmetry at the 50% clench level and after 4 weeks of appliance use. The authors conclude, "The main short term effects of the stabilization appliance on the masticatory muscle activity during submaximal clenching efforts are a reduction in temporal muscle activity and an improvement in masseter muscle asymmetry."

64. **Nakamura, T., Inoue, T., Ishigaki, S., Morimoto, T., and Maruyama, T. Differences in mandibular movements and muscle activities between natural and guided chewing cycles. *Int J. Prosthodont* 2:249-253, 1989.**

Twenty subjects with no symptoms of TMD) were monitored with the Mandibular Kinesiograph and surface EMG of the masseter and digastric muscles. With different types of food both masseter and digastric burst of activity were shortened as the chewing rate increased, with the masseter activity more closely related to the chewing rate than was the digastric activity. When the chewing rate was altered voluntarily, the duration of the digastric burst varied more than the masseteric burst.

65. **Nielsen, I. and Miller, A.T. Response patterns of craniomandibular muscles with and without alterations in sensory feedback. *J. Prosth. Dent.* Vol.593:352-362, March 1988.**

Surface EMG recordings were made from paired anterior temporal, masseter and suprahyoid complex muscles while tracking mandibular movement with a Mandibular Kinesiograph. Twenty normal subjects were monitored for 16 different patterns of response during clenching and mandibular movement. The authors conclusions included, "These data support the concept that movement of the mandible from the intercuspal or rest position develop a coactivation pattern that will excite or inhibit a given muscle regardless of whether clenching with occlusal contacts or no occlusal contacts is involved. The data also demonstrate that the maxillary splint can alter the use of the jaw elevator muscles, predominantly in mastication."

66. **Neill, D.J., Kydd, W.L., Nairn, R.I. and Wilson, J. Functional loading of the dentition during mastication. *J. Prosthet Dent.* 62:218-228, 1989.**

The use of electromyography of the masseter and anterior temporalis muscle to establish an index of chewing force is described. By using the Mandibular Kinesiograph it was possible to determine the interrelationship of the phase of chewing cycle and to measure the duration of each phase. Ten dentate subjects and two completely edentulous denture patients were studied to analyze forces and loading. The authors' state, "...the EMG signal is likely to give us a reasonable indication of the magnitude of the applied load and a valuable method of comparing the force used by a given subject in chewing different food."

67. **Pruim, G.J., Ten-Bosch, J.J., and deJongh, H.J. Jaw muscle EMG-activity and static loading of the mandible. *J. Biomech.* Vol. 11 p 389-395, 1978.**

The study was designed to relate jaw muscle EMG-activity to static (isometric) bite forces. Bipolar surface electrodes were applied to masseter, anterior temporalis and posterior temporalis in combination with small bite transducers. The EMG activity was then correlated with bite force. The authors verified previous investigators findings that there is a linear relationship between integrated EMG-activity and the force exerted by individual muscle during isometric contraction. The role of depressor muscles as elevator antagonists in muscle force analysis was also discussed.

68. **Perry, H.T. Muscular changes associated with temporomandibular joint dysfunction. *J Am Dent Assoc.* Vol.54 p 644-65 3, 1957.**

This retrospective study of 126 TMJ) patients concluded that in every instance where electromyographic evidence of spasm at rest was noted before treatment, the final EMG after treatment indicated a normal or near normal picture of EMG activity. Of the 126 subjects, 118 experienced relief with either occlusal equilibration or occlusal splinting. The EMG was a reliable indicator of the change in resting EMG. The author adds, "In all of the patients studied electromyographically, the pattern of muscle spasm closely followed the topographic distribution of subjectively recognized pain." The author confirms the value of EMG for functional evaluation, "The electromyogram has supplied another useful adjunct in studying functional problems."

69. **Perry, H.T., and Harris, S.C. Role of the neuromuscular system in functional activity of the mandible. *J. Am Dent Assoc.* Vol. 48 p 665-673, June 1954.**

This study of ten patients with normal occlusion studied the activity of the masseter and temporal muscles during gum chewing. The author concluded that as the temporal and masseter muscles reached maximal activity both sides were synchronized, the temporal muscles displayed electrical activity before the masseter muscles; there was greater harmony and smoothness of action-potential discharge on the side preferred for mastication. The author found these patterns different in Class II Division I malocclusion patients and of clinical significance.

70. **Pantaleo, T., Prayer-Galletti, F., Pini-Prato, G., and Prayer-Galletti, S. An electromyographic study in patients with myofascial pain-dysfunction syndrome. Bull Gr Int Rech sc Stomat et Odont. Vol. 26, p 167-179, 1983.**

This study of 11 MPD patients and 5 normal control subjects monitored temporalis and masseter activity with bipolar surface EMG electrodes. EMG activity was studied both at rest and during maximal biting in the intercuspal position. The control subjects had significantly less EMG activity at rest than the patient group. All MPD patients had elevated EMG resting activity which was reduced by TENS application and by an occlusal splint. The authors concluded that TENS/occlusal splint therapy effectively reduced both pain and resting EMG activity indicating reduced muscle spasm. All MPD patients displayed abnormal EMG patterns during the maximal bite in intercuspal position. After correction of the occlusal malrelation with splints, EMG patterns improved and appeared more similar to those of control subjects. The authors conclude, "The correction of occlusal position by acrylic splints was able to induce a persistent reduction or a suppression of the abnormal EMG activity at rest and a good relief of pain; moreover, after the correction, higher levels of EMG activity were found during maximal biting in the intercuspal position."

71. **Riise, C., and Sheikholeslam, A. The influence of experimental interfering occlusal contacts on the postural activity of the anterior temporal and masseter muscles in young adults. J. Oral Rehab. Vol. 9 p 419-425, 1982.**

This study of 11 asymptomatic subjects with full dentitions using surface EMG electrodes examined the effect of intercuspal occlusal interferences on the pattern of anterior temporalis and masseter postural activity. The pattern of postural activity is influenced by the introduction of an experimental occlusal interference. "One week after the insertion of the interference there was still a significant increase of postural activity in either the right or left temporal muscle while there was no significant change in the masseter muscles. Immediately after removal of the remaining interference there was no significant response in the pattern of postural activity. One week later the postural activity had returned almost to its original pattern in all subjects."

72. **Riise, C., and Sheikholeslam, A. Influence of experimental interfering occlusal contacts on the activity of the anterior temporal and masseter muscles during mastication. J. Oral Rehab. Vol. lip 325-333, 1984.**

Quantitative electromyography (EMG) was used to study, in eleven subjects with complete natural dentitions, the effects of an experimental intercuspal occlusal interference on the pattern of activity of the anterior temporal and masseter muscles during mastication. The results show that a small occlusal interference (about 0.5) in the intercuspal position can change the coordination pattern of muscle activity during mastication. There was a prolonged contraction time and reduction in temporalis and masseter function in all subjects, especially on the side of the interference. After removal of the interference the pattern of coordination of muscular activity returned almost to the pre-experimental pattern within two weeks."

73. **Sheikholeslam, A., and Riise, C. Influence of experimental interfering occlusal contacts on the activity of the anterior temporalis and masseter muscles during submaximal and maximal bite in the intercuspal position. J. Oral Rehab. Vol. 10, p. 207-214, 1983.**

The effects of an experimental intercuspal occlusal interference on the pattern of anterior temporal and masseter activity during submaximal and maximal bite were studied on 11 subjects. Using bipolar surface EMG electrodes the results show that during maximal and submaximal bite an occlusal interference is able to disturb the almost symmetric pattern of activity in the anterior temporal and masseter muscles. The level of muscle motor unit recruitment during maximal bite decreased significantly in all muscles studied. After eliminating the interference, the muscular coordination pattern improved and the level of motor unit recruitment increased significantly.

74. **Sheikholeslam, A., Moller, E., and Lous, I. Pain, tenderness and strength of human mandibular elevators. Scand J. Dent Res 88:60-66, 1980.**

This study compared the mean EMG amplitude of the temporalis and masseter muscles during maximal bite in the intercuspal position in 39 patients with functional disorders of the chewing apparatus and 45 control subjects. Maximal EMG activity was significantly stronger in the controls than in the patient group. The authors conclude, "We suggest that the weaker elevator muscles of the patients was a predisposing factor making these muscles less fit to endure hyperactivity induced psychologically or as a reflex response to occlusal interferences and functional disorders of the temporomandibular joints or other elements of the oral neuromuscular system. The sample of controls had much stronger elevators, less susceptible to hyperactivity."

75. **Sheikholeslam, A., Holmgren, K., and Riise, C. A clinical and electromyographic study of the long-term effects of an occlusal splint on the temporal and masseter muscles in patients with functional disorders and nocturnal bruxism. J Oral Rehab. Vol. 13 p 137-145, 1986.**
- “The postural activity of the temporal and masseter muscles in thirty-one patients with signs and symptoms of functional disorders were studied: before, during and after 3-6 months of occlusal splint therapy. The fluctuating signs and symptoms, as well as the postural activity of the temporal and masseter muscles were significantly reduced after treatment. Further, the coefficients of correlation within pairs of postural activity of the right and left muscles increased significantly. After cessation of the splint therapy the signs and symptoms recurred to the pre-treatment level within 1-4 weeks in about 80% of the patients. The results indicate that an occlusal splint can eliminate or diminish signs and symptoms of functional disorders and re-establish symmetric and reduced postural activity in the temporal and masseter muscles, which can facilitate procedures, such as functional analysis and occlusal adjustment.”
76. **Sheikholeslam, A., Moller, E., and Lous, I. Postural and maximal activity in elevators of mandible before and after treatment of function disorders. Scand J Dent Res. 90:37-46, 1982.**
- This study of 37 patients before and after treatment of functional disorders of the masticatory system and 43 control subjects demonstrated reduction of postural activity and reduction of signs and symptoms in all muscles studied. In both temporalis and masseter muscles reduced activity after treatment was accompanied by less pain and tenderness. The right and left anterior temporal and masseter muscle recruitment became more symmetrical after treatment. Increased postural activity and pain coincide for the muscles of mastication and pain decreases with EMG activity in response to treatment.
77. **Shen-gen, S., Guan, O., and Cheng-fan, Z. Preliminary study of electromyographic characteristics for distinguishing centric relation and protrusion in edentulous patients. J. of Prosthet Dent. Vol 69, p 171-175, Feb 1993.**
78. **Sherman, R.A. Relationships between jaw pain and jaw muscle contraction level: Underlying factors and treatment effectiveness. J of Prosthet Dent. Vol. 54 1:114-118, July 1985.**
- Using surface EMG of the masseter muscle the author evaluated 27 patients and 14 control subjects to determine the differences in postural (tonic) muscle activity between patients who have jaw pain due only to TMJ problems and those with pain of other origin. Patients with Th4J problems plus bruxing/clenching had EMG levels similar to those with bruxing/clenching only. The levels were far higher than those in the groups with little or no TMJ problems and no pain. These findings support many other studies that show patient groups have significantly elevated postural EMG levels compared to asymptomatic control groups.
79. **Shpuntoff, H., and Shpuntoff, W. A study of physiologic rest position and centric position by electromyography. J Prosthet Dent. Vol. 6, 5:621-628, 1956.**
- Using surface EMG recordings from the masseter muscles of 215 subjects considered normal using the authors criteria The study concluded that EMG can be used to determine physiologic rest position and centric position. There was a characteristic EMG pattern in all 215 patients in the centric position. The authors conclude that all variety of bite registration techniques should be studied and compared using electromyography.
80. **Stohler, C., Yamada, Y., and Ash, M.M. Antagonistic muscle stiffness and associated behavior in the pain dysfunctional state. Helv Odont Acta 29:2,1985, in Schweiz. Mschr. Zahnmed. 95:719-13, 1985.**
- Surface EMG of the supra-hyoid and masseter muscles combined with Mandibular Kinesiograph jaw tracking was used to establish differences in EMG activity during painful and non-painful voluntary jaw movement. Twenty two patients with TMD) were compared to six control subjects with painless clicking and no other symptoms. Electromyography of the masseter and suprahyoid musculature, jaw movement and joint sounds were recorded during 10 open-close-clench cycles. Statistically significant co-contraction was found in the masseter muscles during jaw opening in the pain dysfunction patients. Co-contraction of the suprahyoid muscles during closing was less pronounced. The EMG pattern of co-contraction was significantly different than that observed in non pain subjects.

81. **Stohler, C., and Ash, M.M. Demonstration of chewing motor disorder by recording peripheral correlates of mastication. J. Oral Rehab. Vol. 12 p 49- 57, 1985.**

Chewing motor performance was examined in 21 patients; 12 with TMJ dysfunction, 8 with occlusal trauma and 1 with CNS impairment. Surface electromyography and three-dimensional jaw tracking with the Mandibular Kinesiograph to record jaw movement were used to analyze changes in mandibular movement and muscle activity resulting from increased pain during chewing. The authors conclude, "In comparison to normals, it might be assumed that a modification of the original behavior pattern for a variable period depended upon the severity of the dysfunctional state."

82. **Stohler, C., and Ash, M.M. Excitatory response of jaw elevators associated with sudden discomfort during chewing. J. Oral Rehab. Vol. 13 p 225-233, 1986.**

Patients with pain in the TMJ area during mandibular movement were electromyographically monitored for EMG response of the anterior temporalis and masseter muscles. The electromyographic pattern of these muscles was quantified by root mean square peak voltage and contraction time. Statistical analysis of group data showed significantly prolonged contraction times and greater EMG amplitudes for chewing cycles with pain as compared to chewing cycles without pain. Individual data showed statistically significant differences between painful and non-painful cycles in some cases.

83. **Van Eijden, T.M.G.J, Brugman, P., Weijs, W.A., and Oosting, J. Coactivation of jaw muscles: Recruitment order and level as a function of bite force direction and magnitude. J Biomechanics Vol. 23 5:75-485, 1990.**

Bipolar surface EMG of the masseter, digastric, anterior and posterior temporalis muscles registered muscle activity while the patient produced a bite force of specific direction and magnitude as measured by a three-component force transducer. Vertical, anterior, posterior, lateral and medial force directions were examined; in each direction force levels between SON and maximal voluntary force were produced. The authors conclude "For all muscles and bite force directions EMG increases linearly with bite force between 50N and maximal voluntary force. As EMG activity can be considered an indicator of the degree of neural input to a muscle, this input also increases linearly. An increase in input results in an increase of muscle force by recruitment of new motor units and an increase in firing rate. In the present study no distinction could be made between these two mechanisms.

84. **Vig, P. Electromyography in dental science: A review. Australian Dental Journal, p 3 15-322, Aug 1963.**

The author states, "...Surface electrodes are therefore suitable for the study of integrated activity of the muscle mass immediately beneath them. By suitable, symmetrical placement of these electrodes over paired muscles, their relative activity may be studied at rest and in various movements." The author concludes, "It should be emphasized that electromyography is not a substitute for thorough clinical evaluation. However, it does provide an additional and unique method of examining the behavior of the neuromuscular system as it pertains to dental science."

85. **Visser, A., McCarroll, R.S., and Naeije, M. Masticatory muscle activity in different jaw relations during submaximal clenching efforts. J Dent Res. 71(2):372-379, Feb. 1992.**

The EMG activities of the masseter muscles and the anterior and posterior temporalis muscles were investigated in different vertical and sagittal jaw relations using surface electrodes. Relative muscle activities were quantified by means of the Activity Index and the Asymmetric Index. The changing of vertical dimension and repositioning of the mandible with an occlusal splint decreased the activity of the temporalis muscles. The authors conclude that this may explain the therapeutic effect of occlusal stabilization splints in the treatment of craniomandibular disorder patients.

86. **Williamson, E.H., Hall, J.T., and Zwemer, J.D. Swallowing patterns in human subjects with and without temporomandibular dysfunction. Am J Orthod Dentofac Orthop. 98:507-511, 1990.**

The swallowing patterns of 25 adult orthodontic patients already known to have TMJ dysfunction and 25 adult control subjects without such dysfunction were examined with the aid of the Mandibular Kinesiograph and electromyographic recordings taken when the patients sipped water. Analysis of the data revealed that 19 patients with TMJ dysfunction used a tongue- thrust open-jaw swallowing pattern, while only nine control subjects used such a swallowing pattern. Six of the patients with TMJ dysfunction had an anterior open bite, while none of the control subjects had an anterior open bite. The authors suggest that patients with aberrant swallowing patterns should be examined for TMJ dysfunction.

87. **Wood, W.W. A review of masticatory muscle function. J. Prosthet Dent. Vol. 57, 2:222-232, Feb 1987.**

The author states that, “Surface electrodes are generally regarded as satisfactory for recording global activity of the muscle, but they pick up me activity from surrounding muscles. Even so, surface electrodes have been shown to be effective for recording from both superficial and deep masseter muscles and superficial parts of both anterior and posterior temporal muscles.”

The study of clenching and chewing activity of muscle and how it can be altered to a more favorable situation for each patient concludes that elevator muscles demonstrate maximum activity even when bilateral occlusal contacts occur during clenching in the intercuspal position. The elevator muscles are activated together in the intercuspal zone of tooth contact during chewing when the occlusal contacts are balanced bilaterally in the intercuspal position. Increasing the number of eccentric tooth contacts increases the muscle activity during both chewing and clenching.

88. **Yemm, R. Neurophysiologic Studies of temporomandibular joint dysfunction. Oral Sci Rev. 7:31-53, 1976.**

After extensive review of the literature, and studying the EMG of a group of normal subjects and a group of dysfunctional patients the author concludes, “There is an increasing weight of evidence that hyperactivity of jaw closing muscles may originate in the central nervous system. It is concluded that such centrally induced activity may be sufficient to cause muscle damage, which leads to disturbed function, local pain and tenderness and to pain referred to adjacent structures...The results demonstrate a clear difference between the EMG of the normal group and the patient group.”

ADDENDUM II

A SELECTION OF PUBLISHED ARTICLES OF CLINICAL
INTEREST IN NEUROMUSCULAR DENTISTRY
1987 – 2009

By

Myotronics-Noromed, Inc.

December 2009

Boyd, C.S., Slagle, W.F., Boyd, C.M., Bryant, R.W., and Wiygul, J.P. The Effect of head position on electromyographic evaluations of representative mandibular positioning muscle Groups. *Cranio*. Vol. 5, No. 1, January 1987.

The results of this investigation indicate that the electromyographic responses of the masticatory muscles are modified by head position. Dorsal extension increased activity of the temporalis muscles, and ventral flexion increased activity of the masseter and digastric muscles. Of practical significance, it would appear that voluntary alteration of head posture affects the activity of the musculature.

The importance of head position becomes relative to many areas of dentistry such as bite registration for full denture, fixed reconstruction, orthodontic diagnosis, and treatment of temporomandibular joint dysfunction and myofascial pain and dysfunction when this important finding is considered.

Gay, T., Bertolami, C.N., Donoff, R.B., Keith, D.A., and Kelly, J.P. The acoustical characteristics of the normal and abnormal temporomandibular joint. *J. Oral Maxillofac Surg*. Vol. 45. 1987.

This paper describes the results of a clinical study that recorded and analyzed sounds emitted from the temporomandibular joint (TMJ) during simple function as a means for differentially diagnosing disorders of the joint. The technique is based on the principle that each different disorder of the TMJ produces a different effect on the mechanical relationship between the articulating surfaces of the joint, and that these mechanical effects can be determined by analyzing joint sounds in relation to joint movement. A total of 79 patients (101 joints) were studied; 32 (46 joints) were diagnosed as having extracapsular disorders, (primarily MPD), 27 (32 joints) were diagnosed as having a displaced disc with reduction, nine (10 joints) were diagnosed as having a displaced disc without reduction, and 11 (13 joints) were diagnosed as degenerative disease (osteoarthritis/arthrosis). In addition, 25 adults (50 joints) with normal TMJs were included as controls. The results of this study demonstrated that each specific disease of the TMJ is characterized by a unique relationship between the sounds propagated by the joint and the movement of the joint. Essentially, an extracapsular disease was characterized by acoustic quiescence during natural (as opposed to maximal) jaw movement, an internal derangement by a usually symmetrical short duration click/reciprocal click, or random click complex, depending on the subcategory of the disorder, and a degenerative disease by a long duration noise during either or both jaw opening and closing. The data further suggest that the technique serves to reflect the mechanical events (and abnormalities) that are involved in function of the diseased joint and has potential for use as a clinical diagnostic tool.

Konchak, P.A., Thomas, N.R., Lanigan, D.T., and Devon, R. Vertical dimension and freeway space: A kinesiographic study. *The Angle Orthodontist*, April 1987.

A statistical correlation is found between the S-N/mandibular plane angle and clinical freeway space, but there was no correlation after TENS stimulation. The S-N/MP angle did not prove to be a reliable predictor of freeway space.

Cooper, B.C. Myofacial pain dysfunction: A case report. *Cranio*. Vol. 6, No. 4, October 1988.

This article follows the case of a 16-year-old female in whom myofacial pain dysfunction was precipitated by the physical trauma of a bicycle accident, ultimately resulting in a maximum interincisal opening of 8mm. The practitioner's therapeutic goal was to fully relax the musculature and reposition the mandible with an anatomically accurate orthotic to maintain optimal muscle function without accommodative function.

Fagan, M.J. The need for integrating TMJ therapy with implant prosthodontic cases. *NY State Dent. Journ*. Vol 55, No. 4, pp. 29-32, April 1989.

In this paper, guidelines for TMJ diagnosis and treatment were reviewed, and a case history was presented demonstrating the need for the integration of TMJ therapy. The case history presented is just one of many cases in the author's practice where the implant candidate also presented with a CM-TMJ disorder. The author emphasizes the incorporation of a CM-TMJ disorder screening exam and history to complement the initial consultation by all practitioners. This should include: 1) check for pops, clicks, in front of ears, (opening, closing, protruding); 2) range of motion (three fingers opening); 3) headaches; 4) grind or brux (night or day); 5) palpate key masticatory muscles of the head and neck; 6) tooth interferences; and 7) bite feels off. The author understands that not all practitioners have access to various diagnostic instrumentation, but emphasizes that this should not prevent the practitioner from diagnosing and treating CM-TMJ disorders or referring for such treatment. The literature has not indicated the overall benefits of implant prosthodontics other than allowing mastication of food and a feeling of self-esteem; but the benefits also allow the treatment and relief of CM-TMJ disorders via a stable occlusion.

Fagan, M.J., III. Neuromuscular concepts in prosthodontics. Implant Prosth: Surgical and prosthetic techniques for dental implants. Yearbook Publishers, MA 1990, Chapter 12, pp 173-196.

In this book chapter, the author makes the case for routinely incorporating TMD screening and history to complement the initial implant consultation. He also discusses how the neuromuscular approach can aid in pre-surgical planning and may open additional options for treatment.

Thomas, N.R. Pathophysiology of head and neck musculoskeletal disorders: The effect of fatigue and TENS on the EMG mean power frequency. Frontiers of Oral Physiology. Vol. 7, pp. 162-170, 1990.

This study using 21 randomly selected subjects was done to demonstrate how spectral analysis of the surface EMG signal can sometimes produce valuable objective data for the diagnostic process when EMG amplitude alone would not. Simply stated, amplitude alone may indicate a resting muscle status, whereas mean power frequency analysis of that same muscle may indicate that the low amplitude reading is due to fatigue.

Langberg, G.J. Computerized Mandibular Scanner: A valid adjunct to magnetic resonance imaging for the diagnosis of internal derangement of the temporomandibular joint. Bergamini M (ed): Pathophysiology of head and neck musculoskeletal disorders. Front Oral Physiol. Basel, Karger, 1990, Vol 7, pp 5 2—66

In a study of 21 patients, 17 females and 4 males with an average age of 29.95 years, the computer mandibular scanner aided in efficacy of diagnosis in 20 of 21 patients.

These preliminary results would tend to indicate that the computer mandibular scanner may be valid as a diagnostic modality for diagnosis of internal derangement of the TMJ.

It would be worthwhile to evaluate whether the computer mandibular scanner can document medial displacement of the disk. The true worth of the MRI is that it performs an elegant function in this facet of imaging where other modalities seem to fall short.

Yamashita, A and Yatani, H. Occlusal bonding for long-term neuromuscular occlusion. NY State Dent. Journ. Vol. 56, No. 4, April 1990.

Langberg, G.J. Ultra-low-frequency TENS: A well-kept secret. Pain Management. Clinical Tips. Sept-Oct. 1990.

Lynn, J. and Mazzocco, M. Computerized mandibular motion analysis: A physiologic perspective. Computers in Clinical Dentistry. September 1991.

In this well-referenced book chapter, the authors review the literature related to the anatomy and biochemistry of occlusion and its role in relation to headache. They also review the apparatus and procedures used for computerized mandibular motion analysis, surface EMG of the masticatory muscles, and computerized study of TM joint sounds as an aid in occlusal evaluation and in achieving a true physiological rest position of the mandible.

Coy, R.E, Flocken, J.E, and Adib, F. Musculoskeletal etiology and therapy of craniomandibular pain and dysfunction. Cranio Clinics Intl, Williams and Wilkens, Baltimore, 1991. pp 163-173.

The investigators sent questionnaires and guidelines for submission of case histories to Fellows of the International College of Craniomandibular Orthopedics, who are geographically dispersed over the United States. The practitioners were requested to supply data and case histories on patients who were treated specifically for Craniomandibular pain or dysfunction. Sixty-eight case histories received from 20 practitioners that met the study guidelines were included. The data reported in these case histories indicate that a common measurable etiology is responsible for the many ostensibly diverse manifestations of craniomandibular pain and dysfunction. The diagnostic validity and usefulness of the electronically derived quantitative data are supported by the correlative subjective perception by the patient of alleviation of symptoms in response to the correction of skeletal malrelation and the consequent reduction of muscle tension. The course of treatment provides rapid initial palliation followed by long-term resolution as a result of orthopedic correction of skeletal malrelation. The continuing positive responses to this noninvasive treatment based on quantitative as well as subjective diagnosis indicate the need in every case of craniomandibular pain or dysfunction to rule in or rule out musculoskeletal dysfunction as the most common underlying etiologic factor in most aspects of craniomandibular pain and dysfunction.

Jankelson, R.R. Validity of SEMG as the “gold standard” for measuring muscle postural tonicity in TMD patients. Anthology of ICCMO. Vol. II, 103-25. 1992.

Whenever possible, any disease or dysfunctional state must be reduced to a cellular/histochemical model. The literature is definitive that muscle hypertonicity is characteristic of TMD. The histochemical state of hypertonic craniomandibular skeletal muscle follows that of hypertonic skeletal muscles in other anatomic areas of the body. All biologic models suggest the cellular electrical phenomena being measured is a summation of terminal efferent transmembrane potentials resulting from both somatic and psychogenic factors contributing to postural tonicity. Starting from a ceded premise that monitoring postural tonicity with EMG biofeedback is a rational and recognized clinical procedure, the scientific evidence affirms that intra-subject EMG monitoring of postural states is a rational and recognized procedure. Investigators and clinicians recognize that manual palpation is not a reliable indicator of the histochemical electrical status of hypertonic muscle. However, EMG is well established as the “gold standard” for measuring hypertonic states in the medical profession. It is also universally understood that lowering postural hypertonicity is a desired therapeutic objective for management of musculoskeletal dysfunction at any level of the human postural chain.

Jankelson, R.R. Temporomandibular Joint Sounds: A Scientific Review. Myotronics, Inc. 1992.

Combadaou, J.C., and Combelles, P.R. The efficacy of sonography in the diagnosis of joint disorders. Anthology of ICCMO, Vol II, 207-14, 1992.

Bergamini, M.F., and Prayer-Galletti, S.U. Systematic manifestations of musculoskeletal disorders related to masticatory dysfunctions: The effect of fatigue and TENS on the EMG mean power frequency. Anthology of ICCMO, Vol II, 89-102, 1992.

Butterworth, J.C., and Deardorff, W.W. Passive eruption in the treatment of craniomandibular dysfunction: A post treatment study of 151 patients. J. Prosth. Dent. Vol. 67, No. 1, April 1992.

There is a sparse post treatment evaluation of craniomandibular dysfunction (CMD). This study describes the use of an orthopedic interocclusal appliance with passive eruption for the treatment of CMD. The clinical results of 151 patients treated using the passive eruption procedures were assessed at a follow-up time averaging 1.75 years after treatment with a highly structured telephone interview questionnaire. The treated patient population was chronic, averaging 2.58 years in pain and 2.25 previously ineffective treatments for their CMD. Although this was a subjective inquiry, the treated patients confirmed significant reductions in symptoms, a decrease in pain and interference ratings, and reduced health care utilization. A subgroup of 38 patients who previously had no relief with flat-plane therapy exhibited similar positive results. Treatment failures were also assessed but were low. The results are discussed in terms of the patients’ support of the efficacy of the passive eruption procedure, including the need for future research.

Morgan, D.H. Tinnitus of TMJ origin: A preliminary report. Cranio. 1992 Apr; 10 (2):124-9.

Twenty patients whose chief complaint was tinnitus were examined. They were not known to have temporomandibular disorders. They did not have pain or dysfunction. They were examined by physicians for ear disorders and the results were considered negative. Each of these patients had a complete history and clinical temporomandibular joint examination. The clinical examination included muscle and joint palpation and stethoscopic examination of the joint. This examination also included selected computerized mandibular scans and electromyographic studies of selected facial muscles. Each subject had eight views of transcranial lateral oblique x-rays taken. It was determined that 19 of these individuals had one or more clinical, electromyographic, and radiographic indications of a temporomandibular disorder. From this study, it appears that individuals who have tinnitus with no apparent otologic basis for this symptom should have a careful evaluation of the temporomandibular apparatus. A temporomandibular disorder may be one of the primary causes of this symptom.

Garry, J.F. Craniomandibular pain and dysfunction of elusive occlusal origin. Am. J. Pain Management. Vol. 3, no. 4, October 1993.

The case described is that of a 57 year old white female who, in her nine-year search for relief from craniofacial pain, was seen by 103 different health professionals. The patient had documented expenses in excess of \$300,000 for previous diagnostic, therapeutic, and pharmacologic procedures. Through previous treatment, she gained no more than brief, temporary periods of relief. A successful diagnosis and subsequent management of her case with the aid of electronic diagnostic modalities is described. The approach described has resulted in her now having been symptom-free for over eight years.

Lynn, J.M., and Mazzocco, M.W. Neuromuscular differentiation of craniocervical pain: Is it headache or TMD? Am. J. Pain Management. Vol. 3, No. 4, October 1993.

Clinicians confronted with patients suffering with chronic headache and/or craniocervical pain often must face diverse possibilities in their development of a differential diagnosis. Because of the extensive anatomic, physiologic and biochemical interactions, many disease processes will manifest with similar and overlapping symptoms. Successful treatment of these individuals relies on accurate diagnoses; incorrect diagnoses will most likely lead to disappointing therapeutic outcomes. This review of the literature examines previous conceptual philosophies for the evaluation of patients with craniocervical pain and clearly leads the clinician to conclude that a multidisciplinary approach is indicated for these patients. This article also includes relevant material to allow clinicians to begin to assess their patients in a more effective manner.

Jarmek, G. Lactic acid: Psychological versus physiological ramifications with a case history. Anthology of ICCMO, Vol III, 301-23, 1994.

Bergamini, M.F., Pantaleo, T., and Prayer-Galletti, S.U. Neurophysiological mechanisms involved in the mediation and control of musculoskeletal pain as a basis for the therapeutic approach. Anthology of ICCMO, Vol III, 7-32, 1994.

Cooper, B.C. and Cooper, D.L. Recognizing otolaryngologic symptoms in patients with temporomandibular disorders. Anthology of ICCMO, Vol III, 105-22, 1994.

Temporomandibular disorders (TMD) afflict millions of men, women and children. Although the management of these disorders has traditionally been the purview of dentistry, the most common symptoms are otolaryngologic. The involvement of an otolaryngologist was important and necessary in the role of primary diagnostician and as a secondary diagnostician to rule out primary otolaryngologic disease in many of the 2,760 patients evaluated over the past 13 years. In 996 patients referred to the Center for Myofascial Pain/TMJ Therapy from the Otolaryngology Clinic of the New York Eye and Ear Infirmary, 85% complained of ear symptoms, including otalgia (64%), dizziness (42%), and muffling (30%). Sixty percent complained of throat symptoms, while headaches were reported by 81%. In 1,764 private patients evaluated for TMD, 53% were seen and/or referred by an otolaryngologist. The dentist and otolaryngologist must act as a team in recognizing and diagnosing TMD. As many of the symptoms of TMD fall within the purview of the otolaryngologist, he or she must be cognizant of the clinical presentation of TMD. Likewise, dental practitioners must utilize the services of their medical colleagues to rule out primary otolaryngologic disorders in all patients with suspected TMD.

Moses, A.J. Scientific methodology in temporomandibular disorders. Part II: Ethology. Cranio. Vol 12, No. 3, July 1994.

The historical background of ethology and the paradigm of clinical treatment as scientific experiment, rather than practice of the art of dentistry are discussed. Ethology is defined and explained relative to the study of temporomandibular disorders (TMDs) using instrumentation, measurement and retrospective clinical studies of successfully treated cases as meaningful research for improvement of future treatment.

Cooper, B.C. The role of bioelectronic instruments in the management of TMD. NY State Dent. J. November 1995.

Temporomandibular disorders (TMD) comprise a group of conditions that can affect the form and function of the temporomandibular joint (TMJ), masticatory muscles and dental apparatus. Proper management of TMD by the dentist requires accurate appraisal of the status of the patient's dentition, TMJ and associated neuromuscular apparatus. Certain predefined standards or parameters of function/dysfunction are accepted by the profession. Electronic instrumentation provides objective measurement of many of these biological phenomena, and thus can be used throughout treatment for critical analyses that monitor and enhance treatment efficacy. A treatment protocol for TMD is presented that uses electronic instrumentation to establish a neuromuscular occlusion.

Cooper, B.C. The role of bioelectronic instruments in documenting and managing temporomandibular disorders. J. Amer. Dental Assn. Vol. 127, Nov. 1996.

This reduces the reliance on subjective clinical observations, which, although it is the historical norm, is known to be inaccurate and can lead to errors in diagnosis. TMDs most often manifest themselves with a muscular functional abnormality.

Ferrario, V.F., Sforza, C., Miani, A. Jr., Serrao, G., and Tartaglia, G. Open-close movements in the human temporomandibular joint: Does a pure rotation around the intercondylar hinge axis exist? J. Oral Rehabil, Vol. 23, No.6. June 1996.

Mandibular movement near the maximum intercuspal position was analyzed for the location of the mean instantaneous centre of curvature of the interincisal point path. Measurements were performed using a kinesiograph in 28 healthy young adults with sound dentitions and free from temporomandibular joint disorders. The subjects performed habitual open-close cycles at different speeds; opening movements started from the centric relation occlusion were also analyzed. In none of the 28 subjects was the interincisal point path derived from pure rotation movements performed around the intercondylar axis, not even in the first millimeters of motion. Translation and rotation were always combined, and the position of the centre of curvature changed during the motion, showing different characteristics in the open and closed movements; these patterns were also dependant upon motion speed. The results show that the hinge axis theory cannot explain the mandibular movements because a pure rotation did not occur around the intercondylar axis.

Sakagami, R., and Kato, H. The relationship between the severity of periodontitis and occlusal conditions monitored by the K6 Diagnostic System. J. Oral Rehabil. 1996 Sep; 23(9):615-21.

The occlusal conditions of periodontitis patients were investigated by using a computerized monitoring device. Thirty-three mild to severe periodontitis patients were enrolled in the study and they were categorized into three groups by their periodontitis severity. Each subject answered a preliminary questionnaire, received routine dental examinations, and underwent MKG/EMG tests using the K6 Diagnostic System. Clinical manifestations of periodontitis were confirmed by the questionnaire and the routine clinical examinations. According to the MKG tests, the traces of maximum opening distance and vertical freeway space showed no significant statistical difference among the groups. However, the velocity of terminal tooth contact was significantly delayed in the severe periodontitis group. According to the EMG tests, there was no significant difference in the rest mode EMG activities, but the function mode EMG activities significantly weakened in the severe periodontitis group. These results showed that severe periodontitis patients had poor occlusal conditions that might have been triggered by the instability of centric occlusion due to attachment loss.

Sato, S., Goto, S., Takanezawa, H., Kawamura, H., and Motegi, K. Electromyographic and kinesiographic study in patients with non reducing disk displacement of the temporomandibular joint. Oral Surg. Oral Med. Oral Path. Vol. 81, No.5, May 1996.

OBJECTIVE. The purpose of this study was to clarify electromyographic and mandibular kinesiographic properties of the chewing movements in patients with unilaterally painful nonreducing disk displacement of the temporomandibular joint. **STUDY DESIGN.** Chewing movement in 50 female patients was evaluated by electromyograph and mandibular kinesiograph, and the results were compared with those in 31 normal controls. **RESULTS.** In the analysis by electromyograph, some differences between patients and controls were found. In the analysis by mandibular kinesiograph, chewing movement showed deviation to the chewing side in the TMJ-affected-side chewing but did not show deviation in the TMJ-unaffected-side chewing in the horizontal plane. The maximal anteroposterior width between opening and closing paths in the sagittal plane was smaller in the experimental subjects. **CONCLUSION.** These differences between patients and controls may be helpful to diagnosis for painful nonreducing disk displacement of the temporomandibular joint.

Moses, A.J. Scientific Methodology in Temporomandibular Disorders: Part IV: Evaluation of the TMD Literature Relative to Neuromuscular Instrumentation. Anthology of ICCMO, Vol. IV, 195-206. 1997.

Konoo, Y., and Konoo, T. Chronological change of frequency in sonographic analysis of patients with musculoskeletal disorders. Anthology of ICCMO, Vol. IV, 9-16, 1997.

Kramer, A.J. Headache resolution in a 14-year-old female: A case study of patient with a bilateral tongue thrust, anterior open bite and bilateral open bite, bilateral cross bite, and occlusion on only two teeth. Anth of ICCMO, Vol. IV, 121-28, 1997.

Jankelson, R.R. Effect of vertical and horizontal variants on the resting activity of masticatory muscles. Anthology of ICCMO, Vol. IV, 69-76, 1997.

Combadaou, J.C. Orthopedic treatment of the internal derangements: diagnosis, treatment, and results. Anthology of ICCMO, Vol. IV, 139-47, 1997.

Schottl, R. Craniomandibular Orthopedics: A therapeutic approach to chronic musculoskeletal pain. Anthology of ICCMO, Vol. IV, 99-112, 1997.

Chronic musculoskeletal dysfunction is a frequently overlooked factor in the diagnosis triggerpoints in the sternocleidomastoids of chronic pain, especially in dentistry. It is not sufficient to describe a patient suffering from chronic pain solely in terms of the location of some rotational axis of his mandible in the temporal fossae. Equally, there is no need to give up and view chronic pain as solely psychogenic or as an affliction without cure. Rather, the role of chronic musculoskeletal accommodation as one of the major contributors to chronic pain must be appreciated in order to be able to identify its true etiology and design meaningful therapy. Once the patient is considered as a whole and the necessary interdisciplinary cooperation is established, a functional basis can frequently be reestablished, shaking off the yoke of chronic muscle hyperactivity placing the patient in a more stable and vital position.

Bazzotti, L. Neuromuscular and psychological effects of TENS U.L.F. Electromyographic, kinesigraphic, S.T.A.I. and salivary cortisol measures. Anthology of ICCMO, Vol. IV, 129-37, 1997.

On 52 subjects studied by electromyography and mandibular kinesigraphy, it has been confirmed that TENS U.L.F. produces the effect of neuromuscular relaxation and also the unmasking of the adaptation of the mandibular rest position. The use of S.T.A.I. and salivary cortisol measuring demonstrated no negative influence of this procedure on the emotional status. It is confirmed that TENS U.L.F. is a non-irritant procedure whose effects are well directed towards the neurophysiological system.

Bracco, P., Deregibus, A., Piscetta, R., and Giaretta, G.A. TMJ clicking: A comparison of clinical examination, sonography, & axiography. Cranio. Vol. 15, No. 2, April 1997.

A sample of 30 subjects, 15 with and 15 without subjective temporomandibular joint (TMJ) complaints (noises, sounds), underwent a clinical examination, a sonography and an axiography, to detect TMJ clicking. The clinical examination found 22 noisy joints in a total of 60 TMJs considered. Axiography found 19 noisy joints and sonography 32. While 90% of the examined joints showed agreement between axiography and clinical examination (with a little higher sensitivity demonstrated by clinical examination with respect to axiography), 20% of the joints were positive for clicking in sonography only. Sonography showed a high sensitivity in detection of joint noises which suggests its utility as a screening test for early detection of craniomandibular disorders.

Vargo, C.P., and Hickman, D.M. Cluster-like signs and symptoms respond to myofascial/craniomandibular treatment: A report of two cases. Cranio. 1997 Jan; 15(1):89-93.

Two cases with pain profiles characteristic of cluster-like headache, both within and outside the trigeminal system, are reported. One male patient would typically awaken from sleep with severe unilateral temporal head pain and autonomic signs of ipsilateral lacrimation and nasal congestion. A female patient exhibited severe unilateral boring temporal and suboccipital head pain with associated ipsilateral lacrimation and rhinorrhea. In addition, both patients presented with signs and symptoms of masticatory and/or cervical disorders. These two cases illustrate possible treatment alternatives, as well as possible influences from cervical and masticatory structures in the development of cluster or cluster-like headache.

Cooper, B.C. The role of bioelectronic instrumentation in the documentation and management of temporomandibular disorders. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1997 Jan; 83(1):91-100.

Temporomandibular disorders (TMDs) can affect the form and function of the temporomandibular joint, masticatory muscles, and dental apparatus. Electronic measurement of mandibular movement and masticatory muscle function provides objective data that are defined by commonly accepted parameters in patients with TMDs; these data can then be used to design and monitor therapy and enhance treatment therapy. In this study, data on 3681 patients with TMD are presented, including electronic test data on 1182 treated patients with TMDs. Electronic jaw tracking was used to record mandibular movement and to compare the presenting and therapeutic dental occlusal positions. Electromyography was used to analyze the resting status of masticatory muscles and occlusal function at presentation and after therapeutic intervention. Transcutaneous electrical nerve stimulation therapy relaxed masticatory muscles and aided in the determination of a therapeutic occlusal position. The data show a positive correlation between the clinical symptoms of TMD and the presenting occlusion, accompanied by muscle activity. A strong positive correlation also appears to exist between a therapeutic change in the dental occlusion to a neuromuscularly healthy position with use of a precision orthotic appliance and the significant relief of symptoms within 1 month and at 3 months.

Kasman, G.S, Cram, J.R, and Wolf, S.L. Clinical Applications of Surface Electromyography. Aspen Publications, 1998.

Clinical Applications in Surface Electromyography: Chronic Musculoskeletal Pain offers extensive reference material on the use of surface electromyography (SEMG) in the clinical setting. This book is best suited as a clinical reference, but it could also serve as a supplemental text for an advanced course on the evaluation of orthopaedic conditions.

Bixby, G.K. A clinical technique for the management of a class II skeletal relationship with an anterior open bite as a result of long face syndrome in the adult patient. Functional Ortho. Jan./Feb. 1998

Bazzotti, L. Mandible position and head posture: Electromyography of sternocleidomastoids. Cranio. 1998 Apr; 16(2):100-8.

A study was performed to evaluate relationships between mandible position, dynamics, muscle activity and head posture while swallowing by use of surface EMG and mandible kinesiograph on two population groups (118 pathologic and 31 controls). The study produced the following: 1. specific mandible dynamics with a very fast rising phase (0.3 sec) and longer phase of stabilization (1.5 sec); 2. more than 60% of the subjects presented deglutition at occlusion level, the others swallowing at a distance of 0.1-4.6 mm; 3. the whole muscle activity (temporals, masseters, digastrics, sternocleidomastoids) lasted 1.5 sec with no correlation of duration to age; 4. sternocleidomastoids fired at swallowing with an effort of one-half of temporals or masseters; 6. firing order presented a particular pattern: digastrics more often first, sternocleidomastoids more often last. No differences were found between the pathologic and controls. Findings suggest that the oral phase or mandible dynamic, and the stabilization phase or oropharyngeal phase of swallowing, has an individual role that is important in head postural equilibrium.

Minagi, S., Matsunaga, T., Shibata, T., and Sato, T. An appliance for management of TMJ pain as a complication of Parkinson's Disease. J. of Craniomandibular Practice, January 1998, Vol 16. No.1

This is a case report of a 71 year-old female with pain in the right TMJ, who was also suffering from Parkinson's Disease and was treated using a new intraoral occlusal appliance. The new appliance was designed to limit excessive mandibular excursion to the right side by restricting the mediotrusive movement of the left coronoid process. The appliance significantly suppressed involuntary mandibular excursion

Hickman, D.M., and Cramer, R. The effect of different condylar positions on masticatory muscle electromyographic activity in humans. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998 Jan; 85(1):18-23.

OBJECTIVES: The purpose of this study was to determine a condylar position that permitted the greatest total temporalis and masseter muscle activity in maximum static clench. **STUDY DESIGN:** Twenty normal adults, 9 women and 11 men, were evaluated to determine masseter and temporalis activity in maximum static clench with mandibular condyles in different therapeutic positions. Bimanually manipulated, leaf gauge, centric occlusion, and neuromuscular condylar positions were studied. **RESULTS:** When mandibular condyles were placed anteroinferiorly in a neuromuscular position, total masticatory muscle recruitment was the greatest. In a bimanually manipulated or a leaf gauge position, mandibular condyles were positioned superoposteriorly, producing the least amount of muscle recruitment. **CONCLUSIONS:** The result of any therapeutic position should be an improvement in muscle function. With respect to balance and activation, a neuromuscular condylar position proved to be the position capable of recruiting the greatest motor unit activity when compared with a bimanually manipulated position, a leaf gauge position, and a neuromuscular position.

Deregibus, A., and Bracco, P. Chewing cycle analysis. Anthology of ICCMO. Vol. V, 119-38. 1999.

Diagnostic opportunities of chewing cycle analysis have also been presented. Attention was focused on the possibility of discriminating which joint is primarily involved in the pathology. Interpretation of data considered in this paper came either from a review of the scientific literature or from many years of experience in this field. The authors suggest that daily use of this new diagnostic facility could be useful in both diagnosis and monitoring of therapy. In fact, it must be remembered that the aim of therapy for the dysfunctional patients is not only the resolution of pain, but also the improvement of the functional capabilities.

Peet, E.K., and Clister, K. Changes in craniomandibular neuromuscular function and biomechanics following applied kinesiology diagnostic procedures and manual manipulative therapy. International College of Applied Kinesiology, 1999-2000; 1:125-131

This case report using the Myotronics K6-I bioelectronic measuring device shows improved electromyographic activity and range of movement within the craniomandibular muscles in a patient with jaw pain who had co-management between functional dentistry and Applied Kinesiology (AK). An 11-year-old male had been experiencing symptoms of jaw pain and headaches for 6 weeks following an automobile accident. After AK treatment, a staff technician of the dental office performed the Myotronic K6-I computer assessments on the boy after treatment in a separate room and was blinded from the AK testing and treatment procedures. Graphs presented from the Myotronics instrument showed, post-manipulation, that the boy demonstrated improvement in virtually every measured variable. Subsequent office visits revealed both subjective and objective improvement in his condition. This study demonstrates that AK procedures produced remarkable improvements in TMJ function as documented with the K6-I device. Further research using this kind of instrumentation on larger patient cohorts is warranted.

Thomas, N. Utilization of electromyographic spectral analysis in the diagnosis and treatment of craniomandibular dysfunction. Anth of ICCMO. Vol. V, 159-70. 1999.

Ambroz, C., Scott, A., Ambroz, A., and Talbott, E.O. Chronic low back pain assessment using surface electromyography. Journal of Occupational and Environmental Medicine: June 2000 - Volume 42 - Issue 6 - pp 660-669.

This investigation examined surface electromyography as an additional tool in the comprehensive clinical evaluation of patients with chronic low back pain (CLBP). Electromyographic signals from electrodes placed in the lumbar area of 30 CLBP patients and 30 non-pain control subjects were compared. Patients and controls were matched for age, gender, and body mass index. Paired t test showed a statistically significant difference between the two groups. The muscle activity mean values were threefold higher in CLBP patients than in controls ($P < 0.00001$) in the static testing, and twofold higher in CLBP patients than in controls ($P < 0.00001$) in the dynamic testing. Our findings indicate that surface electromyography assessment of the paraspinal muscle activity may be a useful objective diagnostic tool in the comprehensive evaluation of CLBP.

Dickerson, W., Chan, C., and Mazzocco, M. Concepts of occlusion, the scientific approach: Neuromuscular occlusion. Signature, 2000, Vol. 7, No. 2; pp 14-17.

The neuromuscular occlusal approach is based on the precepts of science. We now have scientific instrumentation that can record and verify the observations and symptoms presented by our patients. Neuromuscular dentistry is the science-based philosophy that has brought further understanding of muscle physiology into clinical dentistry. Many of the questions have now been clearly answered, allowing the neuromuscular dentist to investigate further, opening doors that were previously closed in the realm of dental diagnosis and treatment. The authors believe that everyone is trying to accomplish the same thing – that which is best for our patients. They are happy for everyone who is comfortable with what he or she is doing. For those clinicians uncomfortable with their occlusal expertise, however, and also for those with open minds and the desire to learn as much about the stomatognathic system as possible, this aspect of dentistry may be as transforming as it has been for the authors.

Gerber, J.W. TMD Stabilization: Orthodontic Finishing Success. Functional Orthodontist. Spring 2001.

Ferrario, V.F., Marciandi, P.V., Tartaglia, G.M., Dellavia, C., and Sforza, C. Neuromuscular evaluation of post-orthodontic stability: An experimental protocol. Int J. Adult Orthodon Orthognath Surg. 2002. 17(4):307-13.

To prevent relapse after orthodontic treatment, retention is often considered indispensable. Soft tissues are thought to have a significant influence on dental movements. To quantify the influence of masticatory muscles on post-treatment relapse, and in an attempt to avoid unnecessary procedures, 2 male orthodontic patients (13 and 30 years old at debonding) were followed up. The patients completed 2 years of fixed orthodontic treatment and received no post-orthodontic retention. After 1 week and again after 6 months, alginate impressions of dental arches and a surface electromyographic (EMG) assessment of the masseter and temporalis muscles during maximum voluntary clenching were performed. The younger patient received surface EMG monitoring once a month for the first 6 months and at the 1-year follow-up appointment. Arch dimensions and the 3-dimensional inclination of the facial axis of the clinical crown (FACC) were measured using a computerized digitizer. Symmetry in muscular contraction was measured by the percentage overlapping coefficient (POC), and potential lateral displacing components were assessed by the torque coefficient (TC). At the 6-month follow-up, no clinical modifications were observed. Quantitative evaluation assessed

that arch dimensions had changed slightly (up to 1 mm). While the adolescent patient had no modifications in FACC inclinations, the 30-year-old patient showed significant alterations (up to 18 degrees). In all examinations of the adolescent patient, POC was higher than 86% and TC was lower than 10%. In the adult, POC was inside the normal range, while all TCs were higher than 10.5%. The larger TC measured in the adult may explain the larger modifications in the 3-dimensional position of his dental crowns. In conclusion, a surface EMG assessment may help in the detection of patients who might need post-orthodontic retention.

Barciela Castro, N., Fernandez Varela, J.M., Martin Biedma, B., Rilo Pousa, B., Suarez Quintanilla, J., Gonzalez Bahillo, J., and Varela Patino, P. Analysis of the area and length of masticatory cycles in male and female subjects. J Oral Rehabil. 2002. Dec; 29(12):1160-4.

It is difficult to determine the existence of a normal or physiological masticatory cycle, because there exists great individual diversity. This study presents some data about two parameters of masticatory cycles according to the frontal plane, i.e. the area and length of right-sided and left-sided cycles in a group of 30 young people, 18 women and 12 men. For our study the Myotronics K6-1 kinesiograph was used. It registers the magnetic field and allows us to obtain graphic recordings of the jaw movement in the three space planes. Other authors have analyzed these parameters, but none of those reviewed provides information about the distribution to each side or according to the gender of sampling subjects selected for the analysis. We have tried to describe the normal morphology of the masticatory cycles and, also, establish a reference so as to provide help in the diagnosis of the functional pathology of the masticatory system.

Mazzocco, M.W., and Hickman, D.M. “Space” – the Final Frontier: Use of neuromuscular measurements in clinical treatment. Anthology of ICCMO. Vol. VI, 3-14. 2003.

Losert-Bruggner, B. Comparison of various methods for determination of the therapeutic positioning of the mandible. Anthology of ICCMO. Vol. VI, 36-41. 2003.

Gerber, J. TMD stabilization: Orthodontic finishing success. Anthology of ICCMO. Vol. VI, 113-20. 2003.

Chan, C.A. Treating craniomandibular dysfunctional patients implementing gnathological or neuromuscular concepts. Anthology of ICCMO. Vol. VI, 15-33. 2003.

Treating craniomandibular disorders (CMD or TIVID), is an area of dentistry that has often times frustrated the clinician due to its multi-faceted musculoskeletal occlusal signs and symptoms. An aspect that should be considered in this arena of treatment is the study of occlusion that relates the maxillary and mandibular teeth as well as the temporomandibular joints and the mandible to the cranium. Investigating even further into this arena of occlusion, one discovers that it also involves physiologic dynamics of muscle activity and muscle rest that drives the masticatory element of occlusion. It is the supporting element that is often overlooked in the health care field that allows the human body to posture and optimally function as a complete healthy system. It is apparent after a more thorough understanding, diagnosis and evaluation by the dentist that musculoskeletal, postural, emotional, biochemical and/or functional issues may be part of the suffering patients complaints. Many of the symptoms that accompany this disorder continue to challenge the great minds of the dental profession who may not be aware that the signs and symptoms which are presented go beyond the occlusal perspective of how teeth articulate and where the centricity of condyle to glenoid fossa relationship exists. Traditionally it was believed that these disorders can be treated through gnathological occlusal principles. However, there are fundamental differences between gnathological and neuromuscular approaches in therapy when addressing the needs of patients who present with the numerous signs and symptoms that compromise the craniomandibular dysfunctional patient. These differences are presented in this paper. A clinical case report is presented and reviewed which has been treated gnathologically and later treated neuromuscularly implementing computerized electro-diagnostic and treatment instrumentation validating the often unrecognized differences.

Moschu-Vurtsi, A., and Haralabakis, N.B. Mandibular kinesiography in children with enlarged tonsils before and after tonsillectomy. European Orthodontics Society, 79th Congress Prague, Czech Republic 10 -14, June 2003.

To examine mandibular kinesiography in a group of children before and after tonsillectomy and to evaluate the relationship between enlarged tonsils and jaw movement.

Jones, D.G. Classification: 21st century’s version. J. Amer. Orthodontic Society. Fall 2004.

Bracco, P. Correlation between posture and occlusion. International Congress 2004.

There was a strong relation between mandibular position and body posture: 91 out of 95 (96%) subjects showed variations in load distribution closing mouth either in centric occlusion or in centric relation or in myocentric position. Furthermore, 92 out of 95 (98%) subjects showed changes also in the distance between theoretical and real barycenter on x axis, and 95 cases out of 95 (100%) showed changes on y axis. Similar results were observed by the authors in previous experiences (2). The results seem to support the observation that different jaws relations imply differences in body posture.

Berzin, F. Surface electromyography in the diagnosis of syndromes of the cranio-cervical pain. Brazilian J. Oral Science. July/Sept 2004. Vol. 3. No. 10.

This paper first provides a review of the anatomy and physiology of striated muscles, focusing on the muscle fiber, motor unit and μ neuron. We also commented on the factors that affect the depolarization of this neuron, resulting in its excitation or inhibition, and thereby altering the contractions of the motor unit, which in turn alters the equilibrium of the muscle dynamics. The changes caused by these factors, such as muscular hyperactivity, found mainly in the temporal muscles, with the jaw the resting position and chewing are also discussed. However, muscular hyperactivity is most frequently observed in the masseter muscles. The suprahyoid muscles, responsible for the positioning of the tongue, also show a large number of alterations. We also commented on the changes observed in the contractions of the posterior cranio-cervical musculature, sternocleidomastoid muscles and the upper fibers the trapezius, which are sources of referred pain.

Cooper, B.C. Parameters of an optimal physiological state of the masticatory system: the results of a survey of practitioners using computerized measurement devices. Cranio. 2004 Jul;22(3):220-33.

While bioelectronic instruments have been available for nearly 30 years to assist dentists in day-to-day evaluations of patients' masticatory systems, little guidance has been published to support physiological norms or ideals. An electronic questionnaire was developed and administered to an international group of dentists familiar with the use of bioelectronic instrumentation. Respondents were asked to provide feedback on the norms or ideal parameters of jaw movement, masticatory muscle function with electromyography, and joint sounds through electrosonography that they use in guiding evaluation and treatment of patients with temporomandibular disorders, neuromuscular occlusion, and orthodontics. Surveys were collated to determine areas of consensus. Out of 150 surveys, 55 responses were received from dentists representing nine different countries. Sixty percent of the respondents reported treating more than 150 cases in the past five years using bioelectronic testing. While experience ranged from 2-30 years with different types of devices, average experience was longer with mandibular/jaw tracking (mean 15.3 years) and electromyography (mean 14.1 years) than with electrosonography (mean 7.0 years). Parameters proposed as norms or ideals for electromyographic rest and clench values, and mandibular tracking (velocity, freeway space, and trajectory to closure) were very consistent. Although a smaller number of respondents reported utilization of electrosonography, their criteria for data significance and tissue-type genesis of joint sounds were consistent. While the intra-patient variability may limit the diagnostic use of bioelectronic instruments, the current study demonstrates that through decades of experience, dentists have independently arrived at very consistent definitions of an ideal physiology that can be used to guide treatment.

Chan, C.A. Applying the neuromuscular principles in TMD and orthodontics. J. Am. Orthodontic Soc., pp 20-29, Spring, 2004.

Neuromuscular dentistry goes beyond traditional dentistry in that it includes consideration of the "physiologic posture" of the mandible. Determining habitual posture vs. physiologic posture requires evaluation of the muscles, joints and nerves involved in mandibular posture and function in addition to the teeth. Today's computerized measuring and recording instrumentation, together with an understanding of neuromuscular principles, give dentists the ability to be true "physicians of the mouth." Muscles cannot be evaluated by radiographic analysis alone. With bioinstrumentation it is possible to determine a proper resting jaw position that positively affects the facial, head, and neck muscles and the teeth as well as the joints. A case study is presented in great detail describing how a severe TMD case had failed to respond to long and frustrating traditional dental therapy, but was then resolved through the application of neuromuscular principles and evaluation. Following provisional treatment that proved a symptom-free mandibular position, the case was permanently finished to that position with orthodontic treatment.

Takamatsu, H. Determination of vertical dimension to achieve a functional and esthetic occlusion. Anthology of ICCMO. Vol. VII, 111-22. 2005.

Gleichauf, C. The effect of a neuromuscular physiologic orthosis on masticatory muscle fatigue. Anthology of ICCMO. Vol. VII, 47-56. 2005.

Capmourteres, C. A neuromuscular approach to implant dentistry: A case study. Anthology of ICCMO. Vol. VII, 99-104. 2005.

The use of bioelectronic measurement instrumentation is the only way to create or restore this occlusion, giving the implant dentistry the most predictable result, and avoiding potential complications often associated with implant failures.

As technology advances, the new approach to treatment planning a dental implant rehabilitation should include a thorough clinical examination, complete radiographic evaluation, and a diagnostic wax-up on mounted study models in the neuromuscular occlusal position as determined by TENS. In this author's opinion, this neuromuscular diagnostic protocol, as it was detailed in this case study, will benefit both the patient and the clinician in the quest for achieving predictable results in the future.

Piancino, M.G., Farina, D., Talpone, F., Castroflorio, T., Gassino, G., Margarino, V., and Bracco, P. Surface EMG of jaw-elevator muscles and chewing pattern in complete denture wearers. J Oral Rehabil. 2005 Dec; 32(12):863-70.

The aim of this study was to investigate the adaptation process of masticatory patterns to a new complete denture in edentulous subjects. For this purpose, muscle activity and kinematic parameters of the chewing pattern were simultaneously assessed in seven patients with complete maxillary and mandibular denture. The patients were analyzed (I) with the old denture, (II) with the new denture at the delivery, (III) after 1 month, and (IV) after 3 months from the delivery of the new denture. Surface electromyographic (EMG) signals were recorded from the masseter and temporalis anterior muscles of both sides and jaw movements were tracked measuring the motion of a tiny magnet attached at the lower inter-incisor point. The subjects were asked to chew a bolus on the right and left side. At the delivery of the new denture, peak EMG amplitude of the masseter of the side of the bolus was lower than with the old denture and the masseters of the two sides showed the same intensity of EMG activity, contrary to the case with the old denture. EMG amplitude and asymmetry of the two masseter activities returned as with the old denture in 3 months. The EMG activity in the temporalis anterior was larger with the old denture than in the other conditions. The chewing cycle width and lateral excursion decreased at the delivery of the new denture and recovered after 3 months.

Castroflorio, T., Icardi, K., Torsello, F., Deregibus, A. Debernardi, C., and Bracco, P. Reproducibility of surface electromyography in human masseter and anterior temporalis muscle areas. Cranio. April 2005.

The aim of this study was to test the hypothesis that surface electromyography (sEMG) recordings, made at mandibular rest position from the masseter and temporalis anterior areas, are intra- and inter-session reproducible. A template was designed and built to permit the correct electrode placement from one session to the next session. A sample of 18 subjects was examined. Two groups, homogeneous for age, sex, and craniofacial morphology were selected. The first group included asymptomatic subjects with no signs or symptoms of temporomandibular joint dysfunction (TMD) and the second group included patients suffering from muscle-related TMD. Data were obtained from different sEMG recordings made at mandibular rest position in the same session and in different sessions, repositioning the electrodes using a template designed for that purpose. The electromyograph used in this, study is part of the EMG K6-I Win Diagnostic System. Results showed that reproducibility of sEMG signals from the masseter and anterior temporalis areas at mandibular rest position is possible.

Castroflorio, T., Farina, D., Bottin, A., Piancino, M.G., Bracco, P., and Merletti, R. Surface EMG of jaw elevator muscles: Effect of electrode location and inter-electrode distance. J Oral Rehabil. 2005 Jun 32(6):411-7.

This study addresses methodological issues on surface electromyographic (EMG) signal recording from jaw elevator muscles. The aims were (I) to investigate the sensitivity to electrode displacements of amplitude and spectral surface EMG variables, (II) to analyze if this sensitivity is affected by the inter-electrode distance of the bipolar recording, and (III) to investigate the effect of inter-electrode distance on the estimated amplitude and spectral EMG variables. The superficial masseter and anterior temporalis muscles of 13 subjects were investigated by means of a linear electrode array. The percentage difference in EMG variable estimates from signals detected at different locations over the muscle was larger than 100% of the estimated value. Increasing the inter-electrode distance resulted in a significant reduction of the estimation variability because of electrode displacement. A criterion for electrode placement selection is suggested, with which the sensitivity of EMG variables to small electrode displacements was of the order of 2% for spectral and 6% for amplitude variables. Finally, spectral and, in particular, amplitude EMG variables were very sensitive to inter-electrode distance, which thus should be fixed when subjects or muscles are compared in the same or different experimental conditions.

Chan, C., and Thomas, N.R. Clinical and scientific validation for optimizing the neuromuscular trajectory using the Chan protocol. Anthology of ICCMO. Vol. VII, 3-16. 2005.

Observable effects of anteriorizing the mandible in the frontal/lateral domain has been considered using computerized mandibular scanning confirmed with simultaneous EMGs with ultra low frequency Myomonitor TENS. Tomographic evidence is used to confirm an optimized condylar disc relationship along the optimized neuromuscular trajectory. A clinical comparative study of the classic Scan 4/5 versus the optimized (Chan Scan) was done comprising 73 candidates (43 males, 31 females). Results indicated that 78.5% of all optimized (Chan Scan) trajectories taken were anterior to the classic scan 4/5 trajectory. 21.5% of the optimized (Chan Scan) trajectories were equal to the classic scan 4/5 trajectory. Patient's response to the modified scan was greatly improved over a shorter treatment period than the controls.

Cooper, B.C. Parameters of an optimal physiological state of the masticatory system: The results of a survey of practitioners using computerized measurement devices. Anthology of ICCMO. Vol. VII, 17-33. 2005.

While bioelectronic instruments have been available for nearly 30 years to assist dentists in day-to-day evaluations for patients' masticatory systems, little guidance has been published to support physiological norms or ideals. An electronic questionnaire was developed and administered to an international group of dentists familiar with the use of bioelectronic instrumentation. Respondents were asked to provide feedback on the norms or ideal parameters of jaw movement, masticatory muscle function with electromyography, and joint sounds through electrosonography that they use in guiding evaluation and treatment of patients with temporomandibular disorders, neuromuscular occlusion, and orthodontics. Surveys were collated to determine areas of consensus. Out of 150 surveys, 55 respondents were received from dentists representing 9 different countries. Sixty percent of the respondents reported treating more than 150 cases in the past five years using bioelectronic testing. While experience ranged from 2-30 years with different types of devices, average experience was longer with mandibular/jaw tracking (mean 15.3 years) and electromyography (mean 14.1 years) than with electrosonography (mean 7.0 years). Parameters proposed as norms or ideals for electromyographic rest and clench values, and mandibular tracking (velocity, freeway space, and trajectory to closure) were very consistent. Although a smaller number of respondents reported utilization of electrosonography, their criteria for data significance and tissue-type genesis of joint sounds was consistent. While the intra-patient variability may limit the diagnostic use of bioelectronic instruments, the current study demonstrates that through decades of experience, dentists have independently arrived at very consistent definitions of an ideal physiology that can be used to guide treatment.

Eatmon, R. Changes in mandibular posture after muscle relaxation, using transcutaneous electrical nerve stimulation. Anthology of ICCMO. Vol. VII, 35-46. 2005.

The posture of the body and its related pattern of function with the mechanics of muscles moving bones at the pivot of the joints is the premier focus for physical rehabilitation of neuromuscular pathology. The temporomandibular dysfunction patient likewise must be evaluated and treated with this premise in mind. Postural analysis must be made to try to restore the physiologic alignment of the mandible to the cranial base so that a foundation is established from which to evaluate and plan the management of the case. Successful, non-surgical management has been accomplished by using data obtained from electromyographically testing the muscles of mastication and by using computerized mandibular jaw tracking to help establish the pathology of muscle and skeletal alignments. The posture of the mandible after application of transcutaneous electrical nerve stimulation is measured in its new neuromuscular position to determine what, if any, positional changes do occur.

Bruzzone, G.L. Orthodontic finishing for two TMD patients. Anthology of ICCMO. Vol. VII, 67-90. 2005.

Today, state of the art treatment in orthodontics involves the recognition, diagnosis and stabilization of TMD symptoms prior to orthodontic treatment. The purpose of this paper is to show two severe, yet opposite cases – the short face and the long face – both presenting with TMD problems, and both treated using neuromuscular principles.

Simmons, W.C. Neuromuscular orthotics in the treatment of bruxing and clenching in subjects with and without cervical pathology. Anthology of ICCMO. Vol. VII, 141-48. 2005.

A clinical evaluation of neuromuscularly derived mandibular orthosis in 40 patients diagnosed with bruxism and clenching parafunction is reported. Neuromuscular occlusal orthotics are carefully adjusted utilizing neuromuscular instrumentation and Tek-scan occlusal balancing. Orthotics are monitored for the occurrence of wear facets for a period of six months. Neuromuscularly derived mandibular occlusal orthotics are shown to be effective in the treatment of eccentric bruxism indicating this condition has a direct relationship to occlusal disharmonies. In sharp contrast, clenching parafunction, predominating in patients with cervical dysfunction, was resistant to orthotic therapy. Bruxing and clenching are redefined to reflect a hypothesis of different underlying causes and treatment outcome expectations. Possible physiologic pathways for bruxing and clenching are discussed.

Kares, H. Treatment outcome of myocentric splint therapy aided by a standardized symptom list. Anthology of ICCMO. Vol. VII, 57-64. 2005.

The goal of this study was to prove the effectiveness of myocentric splints on a range of symptoms suffered by CMD patients. The experiment involved the attempt to optimize the indication positioning and prognosis at the start of the dental functional therapy. 62 women and 21 men between 20 and 65 years old were questioned from a list of symptoms at the time a myocentric splint was incorporated and 4 weeks thereafter. We were able to document significant improvements in headaches, joint cracking, facial pain, neck pain and shoulder pain. Symptoms such as ringing in the ears, dizziness and insomnia were improved in approximately 50% of the cases but snoring showed hardly any change.

Ito, M., Okubo, M., Kobayashi, H., Iijima, M., Narita, N., and Matsumoto, T. Trigeminal input modulates acoustic stapedius reflex and inner ear function. IADR Conference Proceedings, Brisbane, Australia, June 28-July 1, 2006.

The aim of this study was to demonstrate the neural connection between trigeminal system and auditory system by means of neurotology devices. Methods: Fourteen healthy volunteer with the mean age of 30 years were participated in this study. Middle and inner ear function were measured with middle ear analyzer (Tympanogram; TG and acoustic stapedius reflex; SR) and distortion product otoacoustic emission (DPOAE) system before and after electrical stimulation of bilateral masseter muscles. The repetitive stimulus, 25 mA for 500 msec at 1.5-second intervals, was applied with TENS unit (Myotronics, Inc.) for 40 min, Each data obtained by middle ear analyzer and DPOAE system before and after stimulation was compared statistically with Wilcoxon signed-ranks test. Results: There was no significant difference in the middle ear function including static compliance showing mobility of tympanic membrane (before: 0.62(0.28)ml after:0.61 (0.3 1)ml), and middle ear pressure (-12.6(11.0)ml -10.3(12.0) daPa). On the other hand, the significant difference was shown in the reflex latency of SR (90.5(24.6) 96.9(29.2) msec, P<0.05). Also, the significant difference was found in DPOAE showing activities of the cochlear hair cells at the level of 1250 Hz (c9.6(5.3)ml 9.2(5.0) dB SPL, P<0.05). Conclusions: This study provides the evidence that electrical stimulation of bilateral masseter muscles can modulate acoustic stapedius reflex and inner ear function. Neurotology devices may become diagnostic tool to evaluate ear symptoms in patients with TMJDs. Further study is needed to clarify the arising mechanism of ear symptoms in patients with TM.TDs.

Deng, M.H., Long, X., Li, X.D., Cheng, V., and Yang, X.W. Clinical application of electrosonography in diagnosis of anterior disc displacement with reduction. L Zhonghua Kou Oiang Yi Xue Za Zhi. 2006 Feb; 41(2):108-10.

The objective of this study was to investigate the electrosonography character of sounds emanating from anterior disc displacement with reduction of TMJ and the value of it in clinical diagnosis. The sounds from healthy TMJ, anterior disc displacement with or without reduction of TMJ, and osteoarthritis of TMJ were recorded and analyzed by K6-I system, then the data was used for diagnosis of anterior disc displacement with reduction in clinic. A special kind of waveform was found in the electrosonography of sounds from anterior disc displacement with reduction repeatedly, and seldom or not in sounds from healthy joints, anterior disc displacement without reduction or osteoarthritis of TMJ. The diagnostic sensitivity of anterior disc displacement with reduction by using electrosonography analysis was 77.2% and specificity was 93.3% when compared with the clinical diagnosis based on clinical appearance and radiography evidence. CONCLUSION: The special kind of waveform may be characteristic wave of sounds from anterior disc displacement with reduction of TMJ, which is useful as an aid in diagnosis of anterior disc displacement with reduction in clinic.

Kato, M, Kogawa, E, Santos, C, and Rodrigues, P. TENS and low-level laser therapy in the management of temporomandibular disorders. J Appl Oral Sci. 2006; 14(2):130-5.

Pain relief and reestablishment of normal jaw function are the main goals of conservative management of Temporomandibular Disorders (TMD). Transcutaneous electrical nerve stimulation (TENS) and laser therapy are part of these modalities, although little is known about their real efficacy in controlled studies. This research compared these two treatments in a sample of 18 patients with chronic TMD of muscular origin, divided into two groups (LASER and TENS). Treatment consisted of ten sessions, in a period of 30 days. Active range of motion (AROM), visual analogue scale (VAS) of pain and muscle (masseter and anterior temporalis) palpation were used for follow-up analysis. Data were analyzed by Friedman test and ANOVA for repeated measurements. Results showed decrease in pain and increase in AROM for both groups ($p < 0.05$), and improvement in muscle tenderness for the LASER group. Authors concluded that both therapies are effective as part of TMD management and a cumulative effect may be responsible for the improvement. Caution is suggested when analyzing these results because of the self-limiting feature of musculoskeletal conditions like TMD.

Deng, M., Long, X., Dong, H., Chen, Y., and Li, X. Electrosonographic characteristics of sounds from temporomandibular joint disc replacement. 1 Int J. Oral Maxillofac Surg. 2006 May; 35(5):456-60.

The purpose of this study was to investigate the waveform and electrosonographic characteristics of sounds emanating from internal derangement of the temporomandibular joint (TMJ). TMJ sounds were recorded from 10 joints of normal people (NP), 10 joints from patients with anterior disc displacement with reduction (DDR) and 20 joints from patients with anterior disc displacement without reduction (DDNR). The sounds were analyzed through fast Fourier transfer methods to observe their waveforms and electrosonographic characteristics. The observations were then used in differentially diagnosing internal derangement. Wave pattern and electrosonography (ESG) differed among the NP, DDR and DDNR groups. There was very little difference in frequency between the sounds from DDR and DDNR, but the amplitude of the DDR sounds was higher than those of DDNR and NP. The sensitivity and specificity of ESG diagnosis for DDR were 77.2% and 93.3%, respectively, while for DDNR they were 81.6% and 64.7%, respectively.

Chan, C.A. Multi-dimensional diagnosis and treatment to avoid orthodontic and surgical pitfalls. J. Amer. Orthodontic Society. Fall 2006.

Clinicians are now realizing that vertical orthopedic eruption of teeth is active throughout life, and with the development of clinical techniques to help in vertical erupting of teeth and increasing the vertical dimension, there is a growing demand to learn how to effectively verticalize and control proprioceptive occlusal inputs from the teeth orthopedically within the neuromuscular parameters of occlusion.⁷ As long as mal-occlusion dominates the musculoskeletal system, mandibular jaw open and closing patterns will be posterior to an isotonic path of physiologic closure. Muscles lengths will foreshorten, resulting in muscular pains and pathologic dysfunction. Optimizing muscular health and identifying muscular disease objectively will increase case stability and improve long term retention. Addressing these orthopedic/functional orthodontic musculoskeletal problems through the eyes of neuromuscular principles will prevent misdiagnosing and mistreatment of the abnormal posterior Class II and abnormal anterior Class III jaw relationships. The significance of the increase in occlusal vertical dimension and its accompanying horizontal change in mandibular position confirms the need to quantitatively measure existing muscle tension and relaxation modes of the masticatory system. These diagnostic tests are clinically useful to assess skeletal mal-relations in evaluating the indications for surgical correction of prognathism or retrognathism. In cases in which the cuspal anatomy has not yet been unduly defaced by wear or extensive restorative treatment, orthodontic vertical eruption alone is the treatment of choice, especially for musculoskeletal dysfunction and temporomandibular joint derangement problems.

Ferrario, V.F, Piancino, M.G., Dellavia, C., Castroflorio, T., Sforza, C., and Bracco, P. Quantitative analysis of the variability of unilateral chewing movements in young adults. *Cranio*. 2006 Oct; 24(4):274-82.

In the current study, a kinesiograph was used to detect and record the three-dimensional motion of the mandibular mid-incisor point during unilateral chewing as a function of time. The aim of the study was to quantify the within-subject short-term reproducibility of the kinesiographic recordings in normal, healthy subjects. Ten seconds of unilateral (right and left) gum chewing were recorded in 20 control subjects using computerized kinesiography. Each subject performed 18 chewing sequences (three repetitions x three sessions x two sides). Chewing cycle duration, volume, standardized depth and width, and the number of reversed cycles were calculated. Intraclass correlation coefficients (two-way random effects analysis of variance with interactions) and paired t-tests were used to compare sessions. For each subject and side, chewing variability was expressed as the coefficient of variation (percentage ratio of standard deviation to mean) of each variable. Mean left and right side mastications were computed over all sessions and subjects. For all the analyzed variables, larger variations between subjects (analysis of variance, $p < 0.001$) than between sessions were found, with intraclass correlation coefficients ranging between 0.432 (left side cycle duration) and 0.989 (right side standardized width). No systematic errors between the three measurement sessions were found for cycle volume and shape (paired t, $p > 0.05$). The highest between subjects/ between sessions variance ratios (up to 223.28) were found for cycle duration and shape. In all subjects, chewing cycle volume was very variable, with mean coefficients of variation up to 47% (left side in females). Cycle duration and standardized depth and width were more reproducible, with mean coefficients of variation up to 10% (duration), 14% (standardized width), and 18% (standardized depth). The spatial characteristics of gum chewing cycles had a large within-subject variability. The temporal and size-standardized (shape) characteristics were more consistent within subject. The results should allow selection of a set of relatively more consistent variables for the definition of normality and the comparison of patients.

Cooper, B.C and Kleinberg, I. Examination of a large patient population for the presence of symptoms and signs of temporomandibular disorders. *Cranio* 2007 Apr; 25(2):14-26.

Temporomandibular Disorder (TMD) is a term generally applied to a condition or conditions characterized by pain and/or dysfunction of the masticatory apparatus. Its characterization has been difficult because of the large number of symptoms and signs attributed to this disorder and to variation in the number and types manifested in any particular patient. For this study, data on 4,528 patients, presenting over a period of 25 years to a single examiner for TMD treatment, was made available for retrospective analysis and determination of whether the TMD care-seeking patient can be profiled, particularly pain difficulties. All patients in this database filled out a questionnaire and were examined for the prevalence of a range of symptoms and clinical examination findings (signs) commonly attributed to TMD. There was no attempt in this study to assign patients to TMD diagnostic subcategories. The data collected were analyzed to determine which of these symptoms and signs were sufficiently "characteristic of the TMD condition" that they might be used in diagnosis, research and treatment, especially in patients needing relief from pain and discomfort. All 4,528 patients reported symptoms and all but 190 of them also showed signs upon examination. Symptoms most commonly reported on the questionnaire included (i) pain (96.1%), (ii) headache (79.3%), (iii) temporomandibular joint discomfort or dysfunction (75.0%) and (iv) ear discomfort or dysfunction (82.4%). In the 4,338 patients who showed signs, the most prevalent was tenderness to palpation of the pterygoid muscles (85.1%), followed by tenderness to palpation of the temporomandibular joints (62.4%). Pain symptoms and signs were often accompanied by compromised mandibular movements, TMJ sounds and dental changes, such as incisal edge wear and excessive overbite. Clearly prevalence of pain disclosed by the symptoms and signs examinations was high. Patients showed variable prevalence and nonprevalence of eight categories of painful symptoms and seven categories of painful signs. Despite the variability, these might be developed in the future into TMD scores or indices for studying and unraveling the TMD conundrum.

Grazia Piancino, M., Farina, D., Merlo, A., Greco, M., Aprato, M., and Bracco, P. Early treatment with "function generating bite" of a left unilateral posterior cross-bite: Chewing pattern before and after therapy with FGB. *IJO*, 2007 Summer, Vol. 18, NO. 2.

A case of a 5.2 years-old child, with a left unilateral posterior cross-bite, from the canine to the second deciduous molar, corrected with the functional appliance "Functional Generating Bite" (FGB) is reported. The chewing cycles were recorded before and 6 months after correction. The number of reverse chewing cycles on the cross-bite/corrected side decreased significantly six months after therapy (2% with the soft bolus and 4% with the hard bolus) with respect to the initial condition (70% with the soft Bolus and 79% with the hard bolus). In conclusion, the FGB achieved the orthodontic correction and also the corrected the masticatory function.

Hickman, D.M., and Stauber, W. Mapping mandibular rest in humans utilizing electromyographic patterns from masticatory muscles. *Cranio*. 2007 Oct; 25(4):264-72.

As the mandible assumes its resting position in space, antagonistic muscles should assume their resting lengths as is demonstrated by resting and isometric electromyography. This zone of mandibular rest can be mapped using these physiologic parameters of muscle activity. Three positions were evaluated: a maximum physiologic open position, a maximum physiologic closed position, and a physiologic rest position. Additionally, each subject's maximum intercuspation position was evaluated. Within the physiologic zone of rest, formed by the maximum physiologic open position and maximum physiologic closed position, muscle recruitment was the greatest in a physiologic group. Results indicated that muscle function was significantly greater within the zone of mandibular rest than at the intercuspation position.

Bergamini, M., Pierleoni, F., Gizdulich, A., and Bergamini, C. Dental occlusion and body posture: a surface EMG study. *Cranio*. Jan 2008; 26(1):25-32.

The objective of this study was to assess, using surface electromyography (EMG), the rest activity of paired sternocleidomastoids, erectors spinae at L4 level, and soleus muscles in a group of 24 volunteer subjects (12 males, 12 females, aged 23-25 yrs) affected by sub-clinical dental malocclusions in different situations of dental occlusion. The subjects' occlusion was balanced (neuromuscularly) (registered on an acrylic wafer). Rest activity was assessed using the sEMG. The measurements were achieved on subjects while standing barefooted, before (Test 1), and 15 minutes after they wore the acrylic wafer (Test 2). The result was a significant reduction of the mean voltage for each muscle. Paired muscles were registered and the balancing rate between right and left muscles showed improvement for all the paired muscles (Wilcoxon test $p < 0.05$). No significant difference was noted in the relaxation and balancing rates between the muscles tested. The data confirmed a beneficial effect of balancing the occlusion with an acrylic wafer on the following paired postural muscles: sternocleidomastoid, erector spinae, and soleus.

Dong, Y., Wang, X.M., Wang, M.Q., and Widmalm, S.E. Asymmetric muscle function in patients with developmental mandibular asymmetry. *J. Oral Rehabil*. 2008 Jan; 35(1):27-36.

The aim was to test the hypothesis that developmental mandibular asymmetry is associated with increased asymmetry in muscle activity. Patients with mandibular condylar and/or ramus hyperplasia having unilateral cross-bite were compared with healthy subjects with normal occlusion. Muscle activity was recorded with surface electrodes in the masseter, suprahyoid, sternocleidomastoid muscle (SCM) and upper trapezius areas during jaw opening-closing-clenching, head-neck flexion-extension, and elevation-lowering of shoulders. Root mean square (RMS) and mean power frequency (MPF) values were calculated and analyzed using anova and t-tests with $P < 0.05$ chosen as significance level. The SCM and masseter muscles showed co-activation during jaw and head movements, significantly more asymmetric in the patients than in the healthy subjects. The RMS and MPF values were higher in the patients than in the controls in the SCM and suprahyoid areas on both sides during jaw opening-closing movement. The results indicate that the ability to perform symmetric jaw and neck muscle activities is disturbed in patients with developmental mandibular asymmetry. The results support that co-activation occurs between jaw and neck muscles during voluntary jaw opening and indicate that postural antigravity reflex activity occurs in the masseter area during head extension. Further studies, where EMG recordings are made from the DMA patients at early stages are required to verify activity sources and test if the asymmetric activity is associated with muscle and joint pain in the jaw and cervical areas.

Cooper, B.C., and Kleinberg, I. Establishment of a temporomandibular physiological state with neuromuscular orthosis treatment affects reduction of TMD symptoms in 313 patients. J. of Craniomandibular Practice, 2008 Apr, Vol. 26, No. 2

The objective of this investigation was to test the hypothesis that alteration of the occlusions of patients suffering from temporomandibular disorders (TMD) to one that is neuromuscularly, rather than anatomically based, would result in reduction or resolution of symptoms that characterize the TMD condition. 313 patients with TMD symptoms were examined for neuromuscular dysfunction, using several electronic instruments before and after treatment intervention. Such instrumentation enabled electromyographic (EMG) measurement of the activities of the masticatory muscles during rest and in function, tracking and assessment of various movements of the mandible, and listening for noises made by the TMJ during movement of the mandible. Ultra low frequency and low amplitude, transcutaneous electrical neural stimulation (TENS) of the mandibular division of the trigeminal nerve (V) was used to relax the masticatory muscles and to facilitate location of a physiological rest position for the mandible. The neuromuscular occlusal position was recorded in the form of a bite registration, which was subsequently used to fabricate a removable mandibular orthotic appliance that could be worn continuously by the patient. Three months of full-time appliance usage showed that the new therapeutic positions remained intact and were associated with improved resting and functioning activities of the masticatory muscles. Patients reported overwhelming symptom relief, including reduction of headaches and other pain symptoms.

Makarita, H.R. Full mouth rehabilitation and bite management of severely worn dentition. J. Cosmetic Dent 24 (2) 85-96, Summer 2008.

This patient initially exhibited severe occlusal disharmony and craniomandibular dysfunction. A series of diagnostic tests using computerized instrumentation was conducted, which provided objective data that was used in treatment planning. Not until the patient's new vertical dimension position was tested for several months was any treatment attempted.

It is well accepted that there is more than one philosophy or method that can be utilized to arrive at a physiologic bite position. As responsible clinicians, we should study the different treatment modalities available to our profession before making a decision as to which one to implement. Whichever method applied it must be in the patients' best interest. Before proceeding to final restorations, it is imperative to establish a comfortable, stable bite derived from verifiable, objective clinical data.

Cooper, B.C. Relationship of temporomandibular disorders to muscle tension-type headaches and a neuromuscular orthosis approach to treatment. J. of Craniomandibular Practice. Vol 27, No. 2, April 2009.

A prominent etiological theory proposed for TMD related headache is that it results from a dysfunctional masticatory muscle system, wherein muscle hyperactivity is frequently caused by dental temporomandibular disharmony. The central goal of this article was to determine from a literature review of the subject whether there is significant evidence to support a relationship between headaches and TMD prevalence. A second purpose was to determine from such a review whether any relationship was one of cause and effect and whether treatment of the TMD condition can result in meaningful reduction or resolution of headaches. In the literature, there was a substantial amount of evidence for a positive relationship between TMD and the prevalence of headaches, and most importantly, that these were the muscle tension-type. Evidence for a cause and effect relationship was strong. It generally showed in numerous patients that TMD treatment of a large number of patients resulted in significant improvement in the physiological state of the masticatory system (muscles, joints and dental occlusion). Reduction or resolution of muscle tension-type headaches that were present was clinically significant. The authors concluded that TMD should be considered and explored as a possible causative factor when attempts are made to determine and resolve the cause of headaches in patients with this affliction. A benefit of resolving headaches at an early stage in their development is that it might result in the reduction of its potential for progression to a chronic and possibly migraine headache condition.

**SELECT STUDIES SUPPORTING THE EFFICACY OF
NEUROMUSCULAR DENTISTRY AND NM OCCLUSION**

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There is a vast body of literature supporting the science of neuromuscular dentistry and neuromuscular occlusion. The following is a partial list of studies that investigate patient population's response to NM treatment. These articles published in refereed journals document the efficacy of neuromuscular principles in the evaluation and treatment of malocclusion.

Cooper, Barry C. (1997) The role of bioelectric instrumentation in the documentation of management of temporomandibular disorders. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 83:1, pp 91-100

Summary: Temporomandibular disorders (TMDs) can affect the form and function of the temporomandibular joint, masticatory muscles and dental apparatus. Electronic measurement of mandibular movement and masticatory muscle function provides objective data that are defined by commonly accepted parameters in patients with TMDs; these data can then be used to design and monitor therapy and enhance treatment therapy. In this study, data on 3681 patients with TMD are presented, including electronic test data on 1182 treated patients with TMDs. Electronic jaw tracking was used to record mandibular movement and to compare the presenting and therapeutic dental occlusal positions.

Electromyography was used to analyze the resting status of masticatory muscles and occlusal function at presentation and after therapeutic intervention. Transcutaneous electrical nerve stimulation therapy relaxed masticatory muscles and aided in the determination of a therapeutic occlusal position. The data show a positive correlation between the clinical symptoms of TMD and the presenting occlusion, accompanied by muscle activity. A strong positive correlation also appears to exist between a therapeutic change in the dental occlusion to a neuromuscularly healthy position with use of a precision orthotic appliance and the significant relief of symptoms within 1 month and at 3 months.

Hickman, D.M., Cramer, R. The effect of different condylar positions on masticatory muscle electromyographic activity in humans. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998 Jul;86(1):2-3.

Objectives: The purpose of this study was to determine a condylar position that permitted the greatest total temporalis and masseter muscle activity in maximum static clench. Study Design: Twenty normal adults, 9 women and 11 men, were evaluated to determine masseter and temporalis activity in maximum static clench with mandibular condyles in different therapeutic positions. Bimanually manipulated, leaf gauge, centric occlusion, and neuromuscular condylar positions were studied. Results: When mandibular condyles were placed anteroinferiorly in a neuromuscular position, total masticatory muscle recruitment was the greatest. In a bimanually manipulated or a leaf gauge position, mandibular condyles were positioned superoposteriorly, producing the least amount of muscle recruitment. Conclusions: The result of any therapeutic position should be an improvement in muscle function. With respect to balance and activation, a neuromuscular condylar position proved to be the position capable of recruiting the greatest motor unit activity when compared with a bimanually manipulated position, a leaf gauge position, and a neuromuscular position.

Hickman, David, M., Cramer, Richard, Stauber, William T. (1993) The effect of four jaw relations on electromyographic activity in human masticatory muscles. Archs Oral Biol 38:3, pp 261-264.

Summary: Significant differences were found in the electromyographic (EMG) activation between the masseter and temporalis muscles for the leaf gauge (LG), manually manipulated (CR) and neuromuscular (NM) bite positions during maximal static clench. The LG position consistently demonstrated the lowest EMG activity, while the NM position displayed the highest degree of muscle activity. Similarly, the ratio of the masseter/temporalis EMG activity during maximal clench was lower for the LG and CR positions and highest for the NM position. These data indicate that the NM position produced the greatest total muscle recruitment, with more masseter involvement during maximal clench, and enabled the subjects to generate greater clenching forces in the NM position as compared to the LG and CR positions.

Lynn, Jack M., Mazzocco, Mike W., Miloser, Stephen J., Zullo, Thomas, (1992) Diagnosis and Treatment of Craniocervical Pain and Headache based on Neuromuscular Parameters, American Journal of Pain Management, 2:3, pp 143-151.

Summary: There is increasing evidence supporting the premise that hypertonicity within facial muscles is an etiologic factor for some chronic headache patients. This muscular hypertonicity is the result of neuromuscular imbalances within the head and neck. Through the analysis of electromyograph (EMG) data, it is possible to construct an intraoral orthosis which creates neuromuscular balance and subsequently relieves the pain.

This study attempted to identify (i) the relationship of EMG-measured dysfunction to reported craniocervical pain and (ii) the effectiveness of EMG-based orthoses on reversing myospastic conditions. Results of the study (N=203) indicate a significant ($p<.0001$) decrease in muscular myospasm at rest and a significant ($p<.0001$) increase in muscular activity during function following treatment with EMG-based orthoses. Reported craniocervical pain was significantly reduced. Results of this study support the hypothesis that creation of a physiologic neuromuscular envelope of craniocervical motion allows reduction of muscular hypertonicity resulting in reduction of pain. Furthermore, utilization of electromyography is a valuable tool during assessment and treatment of chronic facial pain patients.

Coy, Richard E., Flocken, John E., Adib, Fray (1991) Musculoskeletal Etiology and Therapy of Craniomandibular Pain and Dysfunction. Cranio Clinics Intl, Williams and Wilkens, Baltimore, pp 163-173.

Summary: The investigators sent questionnaires and guidelines for submission of case histories to Fellows of the International College of Craniomandibular Orthopedics, who are geographically dispersed over the United States. The practitioners were requested to supply data and case histories on patients who were treated specifically for Craniomandibular pain or dysfunction. Sixty-eight case histories received from 20 practitioners that met the study guidelines were included.

Electronically derived measurement provides an objective quantitative database for diagnosing the existence and extent of myostatic contracture and skeletal malrelation. Compilation of the electronically derived data, correlated with the subjective evaluations of both patient and therapist, establish the existence of significant skeletal malrelation of the mandible to the cranium and consequent myostatic contracture in the pain and dysfunction population. The data reported in these case histories indicate that a common measurable etiology is responsible for the many ostensibly diverse manifestations of craniomandibular pain and dysfunction. The diagnostic validity and usefulness of the electronically derived quantitative data are supported by the correlative subjective perception by the patient of alleviation of symptoms in response to the correction of skeletal malrelation and the consequent reduction of muscle tension (table 7). The course of treatment provides rapid initial palliation followed by long-term resolution as a result of orthopedic correction of skeletal malrelation.

The data clearly established that in the patient population under study:

1. The average electromyograph activity with the patient at rest decreased substantially in the left and right anterior temporalis and masseter muscles after treatment.
2. The average electromyograph activity with the patient clenching increased substantially in the left and right anterior temporalis and masseter muscles after treatment.
3. Following the orthopedic correction of skeletal malrelation, over half of the patients had complete alleviation of symptoms, with the remaining patients experiencing a substantial reduction in the number of their symptoms.

The continuing positive responses to this noninvasive treatment based on quantitative as well as subjective diagnosis indicate the need in every case of craniomandibular pain or dysfunction to rule in or rule out musculoskeletal dysfunction as the most common underlying etiologic factor in most aspects of craniomandibular pain and dysfunction.

In cases in which the data rule out existing musculoskeletal dysfunction as a possible etiology, the patient may then be referred to other appropriate specialties such as neurology, otolaryngology, orthopedics, or psychiatry with the assurance to that specialty that the etiologic possibility of musculoskeletal dysfunction has been explored and ruled out.

Cooper, BC, Kleinberg, I, Establishment of a temporomandibular physiological state with neuromuscular orthosis treatment affects reduction of TMD symptoms in 313 patients. J. Craniomandibular Practice, 2008; 26(2) 104-115

Summary: The objective of this investigation was to test the hypothesis that alteration of the occlusions of patients suffering from temporomandibular disorders (TMD) to one that is neuromuscularly, rather than anatomically based, would result in reduction or resolution of symptoms that characterize the TMD condition. This hypothesis was proven correct in the present study, where 313 patients with TMD symptoms were examined for neuromuscular dysfunction, using several electronic instruments before and after treatment intervention. Such instrumentation enabled electromyographic (EMG) measurement of the activities of the masticatory muscles during rest and in function, tracking and assessment of various movements of the mandible, and listening for noises made by the TMJ during movement of the mandible. Ultra low frequency and low amplitude, transcutaneous electrical neural stimulation (TENS) of the mandibular division of the trigeminal nerve (V) was used to relax the masticatory muscles and to facilitate location of a physiological rest position for the mandible. TENS also made it possible to select positions of the mandible that were most relaxed above and anterior to the rest position when the mandible was moved in an arc that began at rest position. Once identified, the neuromuscular occlusal position was recorded in the form of a bite registration, which was subsequently used to fabricate a removable mandibular orthotic appliance that could be worn continuously by the patient. Such a device facilitated retention and stabilization of the mandible in its new-found physiological position, which was confirmed by follow up testing. Three months of full-time appliance usage showed that the new therapeutic positions achieved remained intact and were associated with improved resting and functioning activities of the masticatory muscles. Patients reported overwhelming symptom relief, including reduction of headaches and other pain symptoms. Experts consider relief of symptoms as the gold standard for assessment of effectiveness of TMD treatment. It is evident that this outcome has been achieved in this study and that taking patients from a less to a more physiological state is an effective means for reducing or eliminating TMD symptoms, especially those related to pain, most notably, headaches.