Stimulation of Bone Healing with Interferential Therapy

Methods of electrical stimulation of bone are reviewed for a comparison with the use of interference currents and for a consideration of the possible merits of various methods. A summary is given of results of treatment of 38 patients with delayed or non-union and predisposition to non-union, and the technique used with Interferential Therapy is described in detail. Results are also given of a study of the effects of stimulation on 11 patients with acute fractures of the tibial shaft, compared with 11 closely matched patients with similar acute fractures who did not receive Interferential Therapy. The advantages of surgically non-invasive techniques are emphasised and recommendations are made for the use of interference currents prophylactically in specific cases.

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Stimulation of the body's natural physiological healing processes with physical methods of treatment is an old therapeutic principle. Changes in rate of healing are most readily apparent clinically and experimentally in superficial tissues where regeneration can be closely observed (Wolcott *et al* 1969, Dyson and Pond 1973, Dyson and Suckling 1978, Nikolova 1987), and where the penetration of electrical, radiant or mechanical energy can have a direct effect on cellular activity and vascular changes.

Clinically, changes in greater depth are assumed when signs of deeper inflammation are rapidly resolved with lasting relief following treatment, whether these changes are brought about through reflex mechanisms and/or by effective localisation of currents or fields at the affected site. Observations of bone repair in humans must rely on clinical tests, radiological appearances and bone scans which will indicate the state of the bone's circulation.

Where trauma or disease has resulted in death of some cells and an abnormal biochemical environment of others with interference in local cellular activities, it has been rational, in view of the bioelectrical nature of the body's metabolic activities, to assume that small electrical convection currents induced in the tissues could be a stimulus for more rapid resumption of normal cellular activities.

The explosion of revived interest in electrotherapy in the last twenty years has stimulated research in biomedical, surgical and other scientific departments. This has resulted in more specific histochemical exploration of the effects of electrical currents on tissue repair to explain some of the changes labelled generally 'alterations in metabolism' (Bassett *et al* 1964, Becker and Murray 1967, Burny, *et al* 1978, Nikolova 1979 and 1987).

Changes have been observed in the activity of enzymes related to tissue repair. Norton *et al* (1977) reported changes in cyclic adenosine monophosphate in epiphyseal cartilage tissues following their electrical stimulation for fifteen minutes. Nikolova and Davidov (1978) also found increased activity of enzymes following interferential therapy in controlled experiments carried out on traumatised sciatic nerves in rats. They reported earlier recovery of the activity of acetylcholinesterase and also sharp increases in the activity of alkaline phosphatases in the affected muscle tissue together with considerable increases in the density of the capillary network. It has been known for many years that increased alkaline phosphatase also accompanies osteoblast activity (Botterell and King 1935). This work and other experiments by Nikolova have now been translated into English and form part of a recently published text book (Nikolova 1987). Results of this author's experiments on treatment of induced hepatitis with interferential therapy were published in *Physiotherapy* (Nikolova *et al* 1984).

Experimental work concerned with the healing potential of electric currents has been most prolific in the area of stimulation of bone repair, where the problem of ununited fractures becomes a serious financial and social burden. Early work in 1953 by the Japanese surgeon Yasuda showed the relationship between mechanical stress and generation of electrical potential in bone. This prompted the extensive experimental work of medical scientists in the sixties and seventies. It has been published in numerous reports, in particular in 1974 in the *Annals of the New York Academy of Sciences* (Volume 238), in *Electric Stimulation of Bone Growth and Repair* edited by Burny *et al* 1978 (resulting from the first European Symposium on Electric Stimulation of Bone Growth and Repair in Brussels in 1976), and in *Clinical Orthopaedics and Related Research* (Volume 124, 1977). This led to numerous clinical trials of various techniques and currents. Small electrodes were surgically implanted inside bone medullary cavities at fracture sites or inserted percutaneously into bone and constant direct current or various forms of pulsed low frequency currents applied by means of batteries. Laboratory experiments continue up to the present time; old experiments repeated and at times with conflicting results.

It is not the purpose of this article to give a detailed account of this work, however some reference to preferred methods of clinical use is necessary in relation to the possible advantages of an alternative method using interference currents with surface electrodes.

Use of Direct Current

Although there had been experimental evidence that unidirectional and alternating pulsed currents were as effective or more effective than constant direct current to increase bone volume (Levy 1974, Klapper and Stallard 1974), surgeons have favoured the use of cathodal electrodes inserted percutaneously at fracture sites, with constant current for a period of at least 12 weeks and the limb non weight bearing (Friedenberg 1971, Brighton *et al* 1975, 1977, Brighton 1980, Connolly 1981, Torbjorn *et al* 1984). Anodes are applied to the skin near the fracture site (Figure 1).

Paterson *et al* (1980) have used surgically implanted cathodes in the form of a helix in the centre of the fracture and a single platinum anode positioned in soft tissues at least 5cms from the cathode for optimum results (Figure 2).

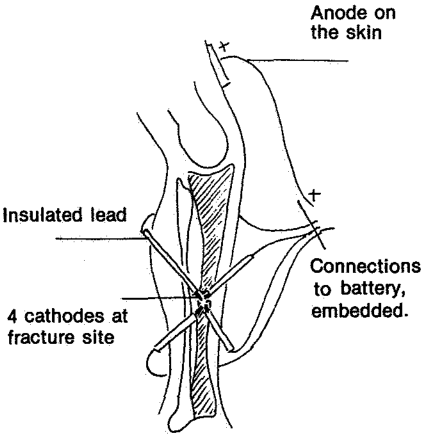


Figure 1: Brighton's semi-invasive technique using Direct Current (Adapted from Brighton *et al* 1977, p.108)

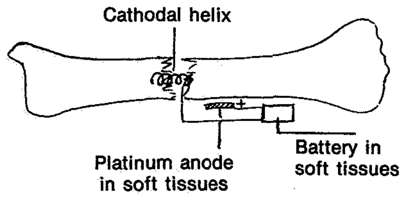


Figure 2: Technique using surgical invasion and Direct Current

Very good results are reported for achievement of bony union. Brighton in 1980 reports 87 per cent success in 131 cases of tibial non-unions. He concludes that because there is no significant difference between such results and those obtained with conventional bone graft surgery, electrical treatment of non-unions promises to become a preferred method.

There is usually no comment in these reports on the overall function of limbs at completion of treatment and the ability of the patient to resume work. This should be an important consideration. Prolonged immobilisation and non weight bearing do not favour functional recovery of joints and muscles and if there is an alternative it should be contemplated when deciding on management.

Use of Electro-magnetic Fields

Bassett and his colleagues appreciated some of the disadvantages of surgical implantation of electrodes (Bassett *et al* 1974, 1977), since:

- most fractures heal without the need for open reduction and therefore applying a surgical procedure unnecessarily cannot be justified
- implanted electrodes require a second surgical procedure to remove them
- implanted electrodes are small and bone formation spatially limited unless multiple electrodes are used
- there are also additional risks including infection.

Bassett *et al* (1974) therefore developed a surgically non-invasive technique using pulsed electro-magnetic fields. This involves little risk to the patient and does not interfere with conservative management. The unit producing the pulsed field is fixed to the plaster and can be connected to a standard plug at home. At least 10 hours of daily use are required for at least three months and no weight bearing is allowed through the limb during this period. There is a detailed report of this technique and results of treatment of 127 cases of ununited tibial diaphyseal fractures, some of the patients having been disabled for more than two years and facing amputation (Bassett *et al* 1981). An 87 per cent success rate was achieved, regardless of age, length of disability, presence of infection or previous operative failures. The technique has also been used in congenital and acquired pseudarthrosis (Bassett *et al* 1977), combined with grafting (Bassett *et al* 1982), to stimulate arthrodesis of the knee (Bigliani *et al* 1983) and for failed posterior lumbar interbody fusion (Simmons 1985). Bassett (1985) quotes a 90 per cent success rate.

Use of a 60 Kilohertz Symmetrical Sine Wave and Two Surface Electrodes

Brighton *et al* (1985) have recently published a preliminary report of electrical stimulation of fractures with established non-union using a 60 kilohertz sine wave (60,000 cps). The current is applied to the skin through two windows on opposite sides of the plaster at the level of the non-union. The power unit is small and strapped to the limb proximally and supplied by a 9 volts transistor-radio battery, replaced each day by the patient. Two leads conduct the current to two small round electrodes 3cm in diameter and the patient applies electrode gel daily to the electrodes. Stimulation is continuous and current on the skin is measured as between 7.1 and 10.5 milliamperes with an effective 5 volts from peak to peak. The involved extremity is immobilized in plaster throughout the stimulation period and until union is achieved.

Twenty-two well established non-unions were treated with an average of 22.5 weeks of treatment. Full weight-bearing was immediately allowed in 4 of the lower limb cases. The other 9 patients with lower limb fractures delayed full weight-bearing for twelve weeks. This difference did not seem to affect the results of union. Of the 22 patients, 17 obtained satisfactory union and remained asymptomatic when followed up except one patient who fell and refractured the scaphoid.

The authors have used the term 'capacitively coupled'' electrical field to describe a displacement current as well as a conduction current through the skin. They conclude that the method has distinct advantages over other methods, as a non-invasive technique allowing weight-bearing.

It is interesting to note that the authors had planned to set up a double-blind study with controls as the treatment was non-invasive. However patients did not agree to a 50 per cent chance of wearing an inactive unit for possibly up to 24 weeks. The present writer appreciates this problem. An alternative is to treat acute fractures with prophylactic stimulation and match them with an acute group without stimulation. This may at least show whether rate of union is hastened by stimulation.

Use of Interference Currents

Prior to all this work, Nikolova in Bulgaria had already used surface electrodes with interference currents for delayed and non-union and other fracture complications since 1963, and prophylactically for recent fractures since 1966. (Duration of non-union not detailed.) Results of comparing various types of physical treatment of 250 patients with retarded callus formation were reported at the 1V Czeckoslovakian Orthopaedic Congress in 1967. The 150 patients treated with interferential therapy had daily treatment for 15 to 20 minutes (in contrast to continuous stimulation with the methods described above), using a 100 cps beat frequency. The number of treatments required to produce union varied between 15 and 50. All the fractures were healed. Fifty of the patients also received anabolic medication during the period of stimulation — 80 per cent of these had also complete functional recovery and 20 per cent only minor residual symptoms — (Nikolova 1969 and 1987). There was full functional recovery in 73 per cent of the patients who had stimulation only and minor residual symptoms in 22 per cent. This work was apparently unknown in most of the western medical world.

In relation to the effect of short bursts of stimulation intermittently, Yasuda had applied electrical stimulation to the muscles of fractured leg bones secured with intramedullary nails, in rabbits. He used four different frequencies, 10, 60, 100 and 250 cps daily for 15 minutes only, on four separate experimental groups. The muscle contractions also imparted vibration to the fractured bones. The most prominent callus formation occurred in the group receiving 10 cps and callus decreased as the frequency of stimuli increased. He found that this bone had a good resonant frequency to 10 cps (Yasuda 1974). Larger human bones would have a lower resonant frequency of vibration.

The weight of experimental and clinical evidence has suggested that an important factor common to all methods of electrical stimulation of healing is a reaction of cells in response to an electrical field rather than to specific polar effects. Various theories have also been proposed relating to physico-chemical mechanisms, with alteration of PH values locally (Wollast *et al* 1978).

The writer had introduced the use of interferential therapy in South Australia in 1970, mainly for painful conditions. The beneficial effects of the currents on inflammatory symptoms were noted clinically (Ganne 1976). The writer decided to investigate its value in 1974 for the treatment of delayed and non-union, based on Nikolova's report. The nature of these currents have been described elsewhere (Ganne 1976, De Domenico 1982, Treffene 1983). There are several advantages to the use of interference currents in bone healing:

- electrodes are applied on the surface and the medium frequency currents are very comfortably tolerated through the skin because of the low impedance to their penetration;
- the treatment is therefore surgically non-invasive but has deep penetration (it was later demonstrated by Laabs that the interferential field is present within the bone at the fracture site, the highest intensity being in the medullary cavity);
- the whole fracture site and areas of bone around it can be exposed to the currents including the osteogenetic periosteal cells and the soft tissues around the fracture, allowing also treatment of any pain and swelling;
- there are no electrolytic effects;
- the nature of the currents with a range of low frequency beats produces therapeutic muscle contractions and this also stimulates bone repair;
- apart from saving time, application of treatment for only short periods

may be advantageous in avoiding tissue accommodation and constant slight irritation, but activating cells at intervals;

- favourable effects have been found clinically and reported experimentally on capillary circulation and inhibition of sympathetic overactivity (Kaindl *et al* 1953, Nikolova 1968 and 1987, Schoeler 1972, Ganne 1980). The significance of adequate blood supply and venous return at fracture sites for repair is well documented (Macnab and de Haas 1974, Rhinelander 1974, Trueta 1963 and 1974, Whiteside and Lesker 1978). The effects on bone blood flow of releasing sympathetic tone was shown by Shim and Patterson in 1966.

Summary of Results of Stimulation Using Interferential Therapy

Over a period of four years 39 patients were referred to the writer for stimulation of bone healing (one of these was bone grafted before completion of treatment). Twenty-five of the patients were referred for delayed or non-union and 22 healed satisfactorily without further management and had no residual loss of function (88%). These cases have been described elsewhere (Ganne 1980); however, of the 9 diaphyseal fractures of the tibia and fibula 7 were healed with an average length of treatment of 7.9 weeks, the shortest period of stimulation being 4 weeks and the longest 13½ weeks. These were severe fractures, five of them compound and four also comminuted. The time interval from date of injury or surgery to referral averaged 20 weeks, minimum period being 11 weeks and maximum 33 weeks. Treatment was given three times a week for 30 minutes.

Thirteen acute cases (including mainly mandibular fractures and spinal fusions) were referred with pain and swelling and predisposition to non-union, *eg* in the case of bilateral fractures of an atrophic mandible. Eleven of these bones healed in average or below average times, one with slight delay and one with considerable delay (Ganne 1979, 1980).

The number of patients referred for this treatment was unfortunately small as clinical investigations were started at this time with surgical implantation of electrodes in the same hospital.

Since 1979 there have continued to be some requests for this treatment in South Australia, depending on the views of individual surgeons and the initiative of physiotherapists.

Method of Stimulation with Interferential Therapy (I.T.)

The aim of the technique is to direct as far as possible the maximum interference at the fracture site and around it (Figure 3).

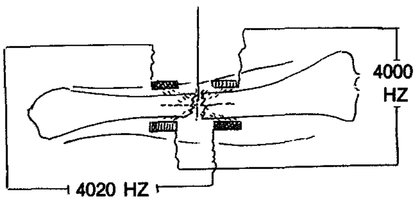


Figure 3: Crossing two medium frequencies using surface electrodes to produce 20 cycles at fracture site

Determination of the Exact Area to Be Treated

The position of the fracture site and its extent and the state of union, if any, must be carefully examined on the X Ray film after reduction, in both the lateral and antero-posterior views. Distances are measured exactly on the film and the measurements transferred to the relevant body area.

For example, in a tibial shaft fracture a measurement is taken of the exact distance between the tip of the medial malleolus and the distal limit of the fracture on the X Ray film; this is then transferred to the patient's limb and marked on the plaster. The proximal limit for the fracture is then marked on the plaster in the same way. This will indicate the exact span of the fracture in length. Bony prominences such as the medial malleolus make useful landmarks when the limb is in plaster and the treatment must be carried out through windows (Figure 4). If the limb is out of plaster, where internal fixation only has been used and the plaster is bivalved, palpation for tenderness and irregularity assists in determining the fracture site, but the X-Ray should still be examined and measurements taken.

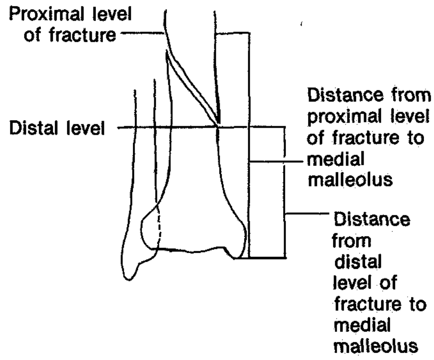


Figure 4: Measuring the level of the fracture on the Xray film

Selection and Position of Electrodes

As in the treatment of joints and soft tissues the size of the electrodes should be sufficient to allow the spread of the interference currents to include all the affected area of bone and the soft tissues adjacent to the fracture. In recent fractures treated prophylactically, there will be local oedema present and possible bruising or a skin laceration or even a deeper wound; this is also usefully included in the field.

Four *separate* electrodes should be used to provide an effective field except for facial fractures and fractures of the metacarpal and phalangeal bones where equal double four-point electrodes are used.

When the limb is in plaster, four windows will have to be cut with an electric saw. It is often necessary and advisable to repair or reinforce the plaster over the fracture site, and above and below it, and allow it to dry for 24 hours before cutting the windows. The writer has often found that plasters are too thin or even cracked. The windows should be very slightly bigger than the electrodes, approximately ½cm all round. For tibial shaft fractures electrodes 4½cm by 6½cm are suitable. The largest electrodes, approximately 14cm by 7½cm are necessary for the femur and for spinal fusions. Around the knee where the circumference of the plaster is greater and the bone end larger, in upper extremity tibial fractures, electrodes 6cm square can be used without danger of weakening the plaster; this size can also be used for humeral shaft fractures which are not in plaster.

The exact position of the electrodes is considered both longitudinally and in cross section. Longitudinally the electrodes should be at least 2cm proximal and distal to the span of the fracture. In cross section the position of the bone within the soft tissues must be considered. In the case of the tibial shaft, the bone is in a medial position, the medial surface being subcutaneous. It is important therefore to place the electrodes in a correct line on either side of the bone medially, both anteriorly and posteriorly and this must be accurately estimated through the plaster (Figures 5a and 5b). The medial edges of the electrodes should just overlap the anterior and medial borders of the tibia. Comparison with the position of the medial surface of the tibia on the unaffected leg is helpful. In practice this is achieved when the lateral edge of the anterior electrodes is approximately in line with the 4th toe. Electrodes are held on the plaster in this estimated position and a line drawn around them ½cm away from the edge. Once cut, the windows are carefully orientated and retained as they will be immediately strapped back into position after treatment. If necessary the plaster is reinforced at this point (Figure 5c). Note that the windows should not be too big, nor over the fracture as this may weaken the fixation and alter the reduction.

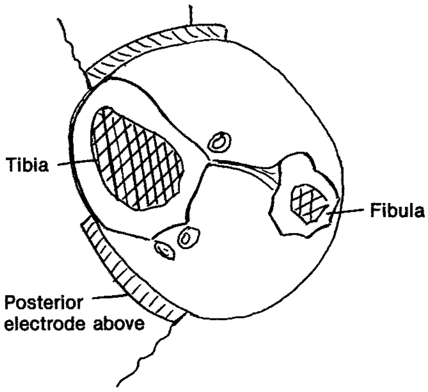


Figure 5a: Right leg cross section showing electrode position

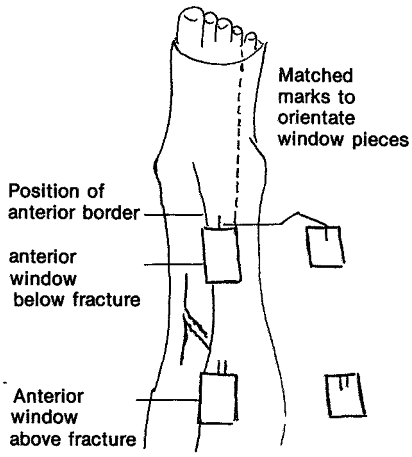
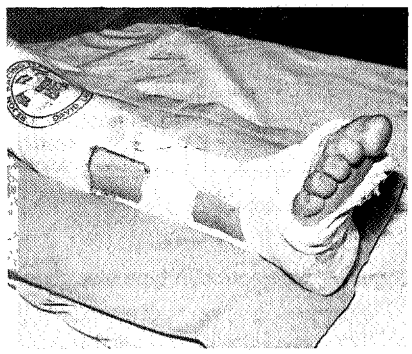
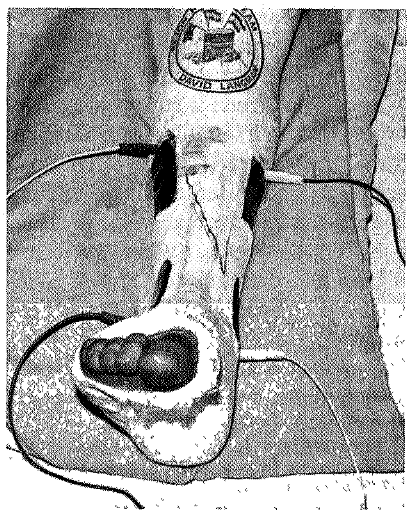


Figure 5b: Right leg in plaster position of windows to stimulate tibia



Postero-lateral windows cut



Electrodes in position

Figure 5c:

If using the Nemectrodyn type electrodes it will be necessary to permanently angle the metal connection to the electrode so that it can project vertically out of the window instead of requiring a larger opening. This is easily done by a technical officer and does not interfere with other treatments, the leads merely being connected at a different angle (Figure 6). When the area is not in plaster, it is obviously possible to vary the position of the electrodes *eg* on a fractured humerus, at times anteroposteriorly and then medio-laterally, depending on the angle of the area still ununited. In the case of a forearm fracture it may be necessary to direct the treatment to one or other bone (Figures 7a,b,c). Limbs out of plaster should be carefully supported during stimulation. If the position is accurate the patient will feel the current as a vibration around the fracture site.

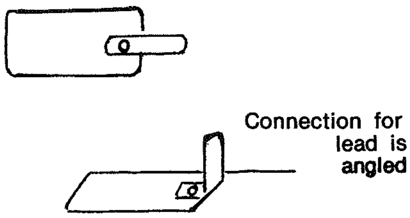


Figure 6: Nemectrodyn type electrodes

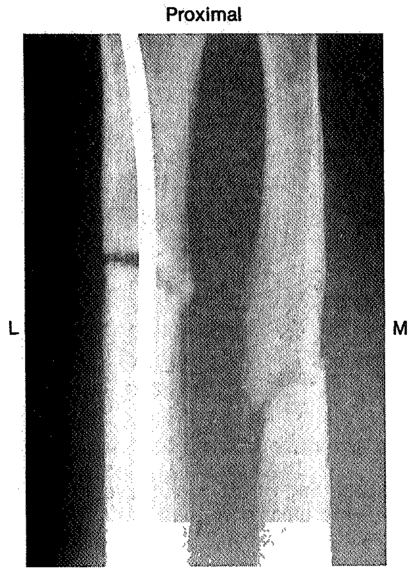


Figure 7a: Fractured L radius and ulna ununited at 13 weeks

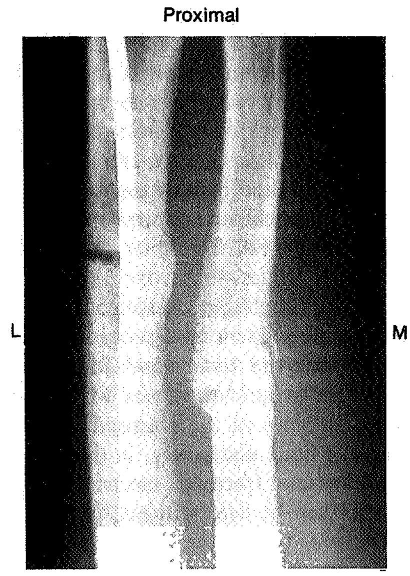


Figure 7c: Six weeks later

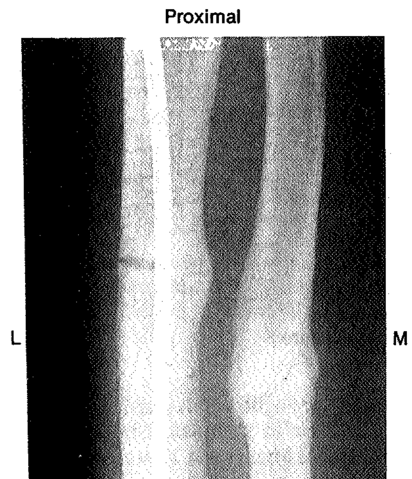


Figure 7b: 10 weeks later after stimulation with IT, clinically united, POP off (treatment ceased)

A wettex pad is placed under the electrode as usual. The electrode is covered with a thick sorbo rubber pad the same size as the window but slightly thicker than the POP to ensure firm contact when the electrode is strapped into the window, with a suitable elastic webbing strap. Note that if there is an open area of skin, a sterile dressing wrung out in a sterile normal saline solution replaces the wettex. (Where there are signs and symptoms of Reflex Sympathetic Dystrophy the limb may benefit appreciably from inhibition of sympathetic tone by treating the relevant ganglion or nerve trunk areas proximally, using 100 cycles).

Selection of Current and Dosage

The dynamic field is preferable, using the vector modulation. In relation to frequency, Nikolova used 100 cycles for delayed union (1969) and this frequency was used by the writer initially. Later the evidence of Yasuda's work on frequency quoted earlier in this article suggested a change to a lower frequency could be more effective, and a constant 20 cycles was selected. The writer experimented personally with the feel of different frequencies on the jaw and with the sensation of vibration in the tibia at different frequencies. To avoid sympathetic stimulation it may be advisable to avoid sustained frequencies below 10 cycles but the frequency can also be set to vary between 10 and 20 cycles per second. In recent fractures treated prophylactically Nikolova (1987) uses a frequency of 0 to 100 initially 'because of its ability to normalise tissue trophicity'. It should be appreciated that there is considerable overlap in the effects of different frequencies on pain and swelling. The 20 cycle frequency used by the writer in experimental work on recent fractures was also significantly effective for pain and swelling compared with controls.

Current intensity should be such as to produce a comfortable contraction of the muscles around the bone and a definite awareness of vibration across the fracture site. This sensation should be carefully sought, controls being adjusted accordingly while questioning the patient. He should feel the muscles gently but firmly 'holding the fracture'. It may be necessary to build up to this intensity in the first two treatments. More current is required to produce this effect when using larger electrodes over a bigger cross sectional area.

Occasionally shunting may occur longitudinally along an intramedullary nail, causing some discomfort from concentration at the extremities of the nail; in this case, the intensity can be kept just below this point of discomfort.

Duration and Frequency of Treatment

Treatment has been given on five days a week in acute cases or three times a week in more chronic delayed

Figure 8: Position of 4 point electrodes for angle fracture of mandible

union or where attendance more than three times a week is a problem. Thirty minutes treatment has been given at each attendance, but twenty minutes only on smaller bones such as the mandible. (Figure 8) Where there is bone infection a longer period of treatments is required; in contrast a fractured metacarpal may require only a few treatments. Patients may be suddenly aware of the difference in sensation from one day to the next when union occurs and slight crepitus disappears. Where this is clear, the author has found from experience that treatment may then cease, but protection should continue until union is demonstrated radiologically and this will be the surgeon's decision.

Experimental Treatment of Eleven Acute Fractures of the Tibia and Fibula

Herbst (1987 p7) has pointed out that 'quantitative evaluation of the healing rate in humans when using different stimulation methods is not possible to-day because of the difficulty of finding a sufficiently homogeneous patient population.'

Table 1:
Tibial experimental group

Sex and age	*Cause of injury*	*Nature of injury*	*Management*	*Union time in weeks*
1. M. 35 Alcoholic.	V.A. (pedestrian)	Oblique, mid-shaft, 100% displaced slight wound.	H nail, P.O.P. (same day)	11 p.op.
2. F. 63	Fall (rotation)	Spiral, lower shaft, 2 cm. displaced.	Screw fixation and P.O.P.	12 p.op.
3. M. 39	V.A. (car)	Oblique, mid-shaft, 75% displaced Lacerated ankles.	Closed, P.O.P. Remanip. wedged H nail at 3 wks. P.O.P.	7.5 p.op.
4. M. 17	V.A. (motorbike)	Transverse, mid. & lower ⅓ junction 100% displaced.	Closed, P.O.P. Remanip. achieved 3/52 slight lat. shift & anterior angulation.	12
5. M. 17	V.A. (motorbike)	Oblique, mid-shaft 75% displaced.	Closed, P.O.P. unstable. H nail 9th day.	9.5 p.op.
7. M. 26	V.A. (motorbike)	Compound, comminuted lower ⅓ deep wound 3 cm.	Closed, P.O.P. Skin graft at 3 wks.	15.5
8. M. 22	V.A. (motorbike)	Oblique, mid-shaft comp. comm. 75% displaced. Wound 3 x 2 cm. Infected.	Closed, P.O.P. unstable. Remanip. H nail 9 wks.	8.5 p.op.
9. M. 30	Sport (knocked over)	Transverse, midshaft, slight displacement.	Closed, P.O.P. (some lateral shift)	11
10 M. 19	Snapped by kick	Transverse, mid. & lower ⅓ junction 25% displaced.	Closed, P.O.P.	8.5
11. M. 29	Slipped on concrete	Spiral, lower ⅓ tibia, upper ⅓ fibula (identical to control).	Screw fixation & P.O.P.	8.5 p.op.
12. M. 21	Fell skiing	Spiral, middle to lower shaft.	Closed, P.O.P. unstable. Screw fixaton, 9th day.	9 p.op.

The results for the control and experimental groups are set out in Table 1 and Table 2. An analysis of the difference between the matched pairs using the t test was calculated ($t = 3.01$). This indicates that there was a significant difference ($p < 0.01$) between the two groups in rate of union.

Table 2:
Tibial control group (previous consecutive 18-month-period)

Sex and age	*Cause of injury*	*Nature of injury*	*Management*	*Union time in weeks*
1. M. 55 Alcoholic	V.A. (pedestrian)	Oblique, mid-shaft, 75% displaced.	Closed, P.O.P. Redisplaced — H nail, 14th day.	30.5 p.op.
2. M. 55	Fall (rotation)	Spiral, lower shaft, 1 cm. displaced.	Screw fixation and P.O.P.	12 p.op.
3. M. 21	V.A. (motorbike)	Oblique, mid-shaft, compound, comm. 50% displaced.	Closed, P.O.P. Redisplaced H nail at 2.5 wks.	16 p.op.
4. M. 21	V.A. (motorbike)	Transverse, mid-shaft, compound, 75% displaced.	Closed, P.O.P. Remanip. 10th day Slight lat. shift and anterior angulation.	27
5. M. 19	Sport (ran into goal post)	Oblique, mid-shaft, 25% displaced.	Screw fixation, P.O.P.	8.5 p.op.
7. M. 57	V.A. (motorbike)	Compound, comminuted, junction up & mid. ⅓.	Closed, P.O.P. Skin graft.	18
8. M. 18 +	V.A. (motorbike)	Oblique, mid-shaft, Compound, comminuted, 75% displaced.	Closed, P.O.P. Remanip. infection. H nail at 2 wks. P.O.P.	28.5 p.op.
9. M. 33	Sport (knocked over)	Oblique, mid. & low ⅓ junction, slight displacement.	Closed, P.O.P. not perfect alignment	14
10. M. 24	Snapped leg against rail.	Transverse, mid-shaft 50% displaced.	Closed, P.O.P.	8
11. M. 37	Slipped on concrete	Spiral, lower ⅓ tibia, upper ⅓ fibula. Identical displ. to Experiment.	Screw fixation, P.O.P.	12.5 p.op.
12. M. 33	Fell from bicycle	Spiral, junction mid. and low, shaft.	Screw fixation P.O.P.	12 p.op.

N.B. Weight bearing policy the same in both groups.
\+ Integrity of P.O.P. was not always maintained in this case, though H nail was stable.
* Case No. 6 could not be included
P.op = Post operation: P.O.P. = Plaster of Paris: V.A. = Vehicular accident

The problems of comparative work may be magnified also by more variables once there is non-union, apart from ethical considerations. With large numbers of patients, results of a method of electrical stimulation of non-union can be compared with published results of success with bone graft surgery. A problem with using a controlled trial is mentioned earlier.

Concerning the effect of IT on initial healing rate the writer obtained information in a trial of IT on a group of 11 acute fractures of the tibia and fibula in a period of 18 months. These cases were all under the care of the same orthopaedic unit. Results were compared with 11 cases treated without IT in the previous consecutive 18 month-period, on the same unit. They were matched closely in relation to the cause of injury, the nature of the fracture and its management. There was a statistically significant difference in the average rate of healing in the two groups: 10.27 weeks in the experimental group and 17 weeks in the control group ($p < 0.01$, using the t test) (Ganne 1980). Rate of healing was therefore below normal average figures, particularly for severe fractures with 100 per cent displacement (Tables 1 and 2). An important additional finding was the excellent and rapid functional recovery of the patients who had IT stimulation and early return to work (Table 3). These results have not previously been published.

The current was applied when the fracture was satisfactorily reduced and the plaster quite dry. The writer believes that stimulation should commence as soon as possible and in the first two weeks at least after reduction. The currents help to control oedema and pain and facilitate the patient's initial ability to contract muscles statically inside the plaster. Tonna and Cronkite in 1961 observed the process of mitosis of periosteal cells following fracture. They found that the initial proliferation starts 16 hours after injury. The reaction was observed along the entire diaphysis. Maximum in-

Table 3:
Summary of results of treatment of tibial fractures

Case no.	*Clinically firm and radiologically progressing*	*Return to work*	*Residual disability (weeks post-reduction)*
1	11 weeks	Wandering Pensioner	None at 24
2	12 weeks	Normal home occupations at 14 weeks	None at 17
3	7.5 weeks	Resume work 20 weeks	None at 12
4	12 weeks	Looking for work at 20 weeks	None at 20
5	9.5 weeks	Resume work 6.5 weeks	None at 13.5
7	15.5 weeks	Continued study	Only ¼ loss of plantar flexion at 8 months
8	8.5 weeks	20 weeks — found a job	None, except 3cm. shortening at 16
9	11 weeks	Resume work 3 weeks	None at 20
10	8.5 weeks	Continued work	None at 14
11	8.5 weeks	Resume work 10 weeks	None at 20
12	9 weeks	Resume work 14 weeks	None at 12
Average rate of union	10.27 weeks		

crease was 32 hours after fracture. After 5 days, proliferation subsided to normal except at the fracture site where it was still above average two weeks later. These observations emphasise the early activity of cells in the healing process and the immediate need for adequate blood supply and control of swelling.

All patients were treated with 20 Hz for 30 minutes, 5 days per week for a total of 15 treatments. Once the 15 treatments were completed the windows were plastered back securely. The patients all took weight as soon as possible and were discharged home between the second and sixth week. The first assessment at six weeks was only a radiological one: the first clinical assessment of union was as near as possible to eight weeks (Figures 9a, b,c,d and 10a,b).

The results obtained even in this small group suggest that ideally stimulation could be used routinely where possible. Time and equipment may not justify this. The treatment should be seriously considered for acute fractures:

- where healing is likely to be slow in patients with more general metabolic problems (alcoholic or osteoporotic conditions);

Proximal

Figure 9a: Acute fracture, Case no 3, re-displaced 3 weeks after injury

Proximal

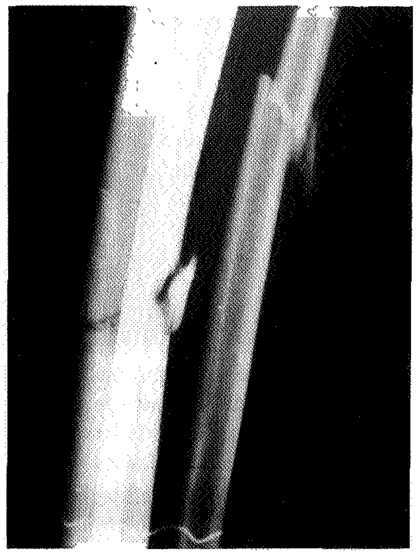


Figure 9b: Hodgkinson nail a week later

Proximal

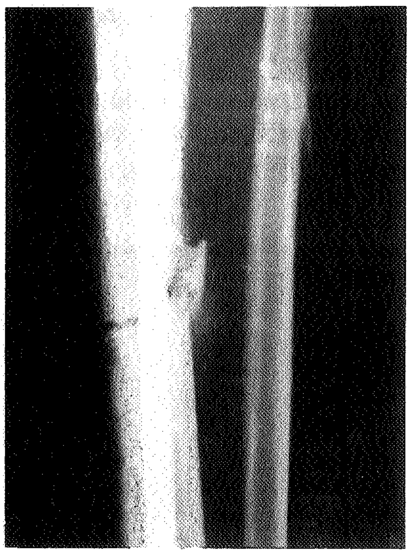


Figure 9c: Case no 3 clinically united at 7.5 weeks post operation
Antero-posterior view

Proximal

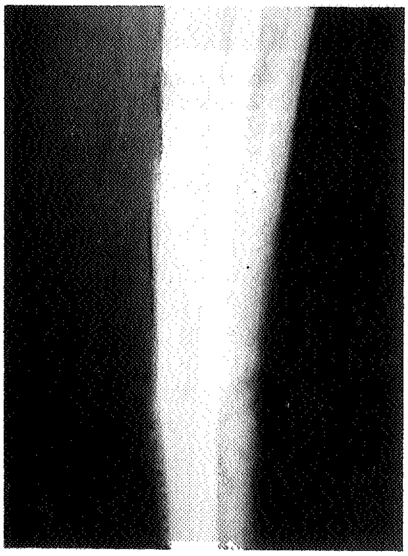


Figure 9d: Case no 3
Lateral view

- to reduce pain and swelling in recent fractures of the mandible which may not require fixation, *eg* condylar fractures,
- in bilateral leg fractures where there is a greater incidence of delayed union with dilatation of vessels in one limb tending to cause simultaneous vasoconstriction in the other (Wray 1963, Rosenthal *et al* 1977);
- bilateral mandibular fractures particularly in edentulous patients where there is likelihood of delayed union (Rowe 1969);
- for tibial shaft fractures that have required two or more manipulations in the first two to three weeks to achieve an acceptable reduction;
- for fractures occurring in competitive sportsmen, particularly tibial shaft fractures and those involving joint surfaces;
- in upper limb fractures in musicians where perfect functional recovery is so important.

Contra-indications to the use of this treatment which may arise in patients with fractures are similar to contra-indications in other cases. It is inadvisable to apply the current to a semi-conscious patient or one with a history of very recent loss of consciousness particularly if the treatment lasts for more than 15 minutes, as the writer has observed that this may cause increased drowsiness after IT, pointing to possible effects on the Reticular Activating Centre. In the case of pathological fractures due to malignancy there are differences of opinion. German authorities state that there is no evidence to suggest that this aggravates the condition (personal communication). The author has not applied the current through an area of the body known to have malignancy. The medical officer should make this decision if he believes it is worth a trial to relieve pain.

Discussion

The problem of establishing whether a fracture considered to have delayed union may heal of its own accord given more time, or become an established case of non-union without some form of intervention is well known. Nicoll in his survey of 705 cases of fractured tibial shafts in 1964 stated that 'the dividing line between delayed union and non-union must perforce remain imprecise in the majority of cases'; he

Proximal

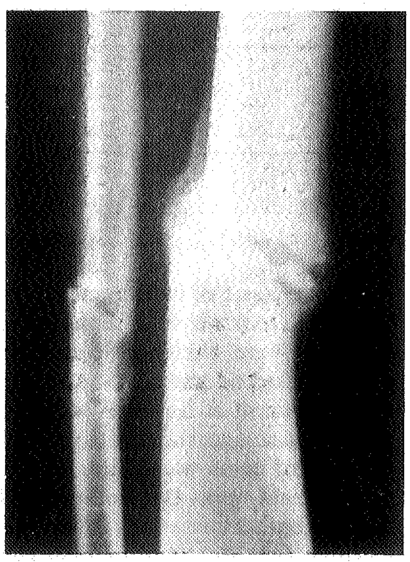


Figure 10a: Acute fracture Case no 10, clinically united at 8.5 weeks
Antero-posterior view

Proximal

Lateral view

defined non-union as those cases in which the surgeon believed that further conservative treatment would not lead to union and recognised that this is often a matter of individual judgement. Others have been more specific, defining delayed union in tibial shafts as a healing time longer than 20 weeks (Ellis 1958, Onnerfalt 1978), or 'no clinical or radiographic evidence of union at four to nine months after fracture' (Bassett *et al* 1981). In such an area of doubt, before resorting to surgery it would seem preferable to institute a trial of electrical stimulation only where progress in healing appears static. The cost of hospitalization, of surgical appliances and operative procedures and the demand for operating theatres would support such a policy. Surgical procedures such as implantation of bone stimulators with invasive techniques have been contemplated or carried out in some cases after three months. Nine of the cases referred to the writer were to have bone grafts when IT was requested as an alternative, and eight obtained union without a graft.

The work of Bassett and Brighton and their colleagues have made it possible to salvage very long established cases of non-union; they refer to one to three year histories of non-union. It is not possible to say whether IT could produce such results, without attempting it. Where treatment is to be continuous for many months it may be preferable to organize home treatment as in Bassett's method or that of Brighton (1985).

There are obvious advantages in being able to treat soft tissues including muscles and also affect arterial circulation and this is not possible with bone stimulation alone. Concerning small areas of stimulation, Brighton and his colleagues have described a new type of cathode designed to improve the distribution of the current in the medullary canal and producing better bone formation experimentally (1981). The modification was to be evaluated clinically.

It is an advantage to be able to proceed with partial to full weight bearing during stimulation from a functional point of view and this did not seem to interfere with healing provided the plaster was intact. Brighton and Bassett stressed the need for no weight bearing at all for 12 weeks with long standing cases of non-union, using some techniques.

Chronic infection may cause delay in undertaking surgical procedures whereas IT has been observed to hasten discharge and resolution.

Some cases of delayed union will require surgical measures, to achieve a stable reduction or where soft tissue is interposed between bone fragments. Some long standing cases have required a combination of bone grafting with electrical stimulation (Basett *et al* 1982)

It was a matter for some concern that in nine of the patients referred to the author the fractures had not always been adequately held throughout the period when healing would be expected to take place and delayed union might have been avoided. From the extensive numbers of reported non-unions in the literature it would seem that better prophylactic care is needed in the form of careful observation and attention to simple details and patient instruction.

The method of stimulation described by Brighton *et al* (1985) is of particular interest as stimulation is applied through surface electrodes and allows weight bearing. The technique does require complete co-operation of the patient. The apparatus is light and portable compared with the pulsed electromagnetic device. In terms of hours, the period of constant stimulation described in this preliminary report was very much longer than that used for IT stimulation, though the non-unions were of longer standing. If a very long period of stimulation is required, home treatment is an advantage and can also be used more easily for country patients. There would be no stimulation of muscle contractions and each patient also requires a separate unit.

It is important to appreciate that electrical treatments can be successful when currents are applied through the skin with appropriate knowledge and understanding, and that implantation of electrodes with surgical invasion is not necessarily required.

Conclusions

There are various advantages in the different methods of electrical stimulation for bone healing. It is apparent that a combination of physiological effects may contribute to the healing process when using IT. The technique used by the author has been described in detail to assist any member of the profession who may be in a position to try a similar approach and to stimulate further clinical research inspite of the problems.

Prophylactic stimulation of acute fractures with Interferential Therapy should be considered more often, particularly where there are factors which predispose to delayed or non-union. It is a method of choice also, using techniques directed at the whole limb where there are signs of Sudeck's atrophy.

In fractures which are considered to have delayed union, a trial of a non-invasive method of stimulation should be preferred which allows weight bearing. If a decision is made to use interferential stimulation this must be given an adequate trial and the technique accurately applied.

Measures to prevent inadequate fixation of fractures should be more rigorous and include detailed instruction of the patient and careful observation by the staff concerned.

Appropriate electrotherapy can hasten resolution of inflammation and repair of tissue and should continue to be offered by physiotherapists. Clinical experience and concern for optimum results at low cost to the community will hopefully reduce the need for repeated complex surgical procedures.

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