CURRENT METHODOLOGICAL APPROACHES IN ORAL, DENTAL AND MAXILLOFACIAL SURGER

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CONTENTS

CHAPTER 1

Zirconia Implants in Oral and Maxillofacial Surgery: Mechanical Behavior, Failure Modes, and Clinical Evidence—A Clinically Oriented Perspective

Betul Gedik[1] & Mehmet Ali Erdem[2]

1. Introduction: Why Zirconia Implants Matter to the OMFS Clinician

Zirconia implants are increasingly discussed in the clinical arena because they address two persistent demands in implant rehabilitation: (i) esthetic stability in thin soft-tissue phenotypes and (ii) metal-free rehabilitation preferences. In day-to-day practice, these demands present most clearly in anterior regions where mucosal translucency, gingival margin stability, and patient-reported esthe-tic satisfaction become critical (Agnini et al., 2023). Zirconia's tooth-like color and favorable soft tissue interaction can therefore appear clinically compelling.

Yet, zirconia is not simply "titanium without the gray shine." Its behavior is governed by ceramic mechanics: high strength under compression, vulnerability under tension, and a failure pattern that tends to be brittle and abrupt (Daou, 2014). This has profound clinical meaning. A titanium implant can sometimes tolerate suboptimal load pat-terns or minor prosthetic imperfections due to its ductility and broader mechanical safety margin. Zirconia generally cannot (Mobilio, Mollica, & Catapano, 2016). The-refore, zirconia implantology is best approached as a risk-managed clinical strategy, not as an esthetic default.

In OMFS, mechanical risk is often amplified: posterior bite forces, frequent need for non-ideal implant positioning, compromi-sed bone quality, and complex reconstructions. The clinician must therefore understand zirconia not only as a material but as a system—implant design, surgical technique, prosthetic architecture, occlusal scheme, and patient habits all interact. This chapter focuses

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on that clinical integration: a mechanistic understanding trans-lated into practical clinical choices.

2. Material Properties with Direct Clinical Implications

2.1 Zirconia as a Structural Ceramic: What the Clinician Must Internalize

Zirconia (typically Y-TZP) is a high-performance ceramic that benefits from transformation toughening, which slows crack propagation under certain stress conditions (Denry & Kelly, 2014). Clinically, this explains why zirconia can demonstrate impressive laboratory fracture loads and why many zirconia implants perform well in low-to-moderate load environments. However, transformation toughening is not the same as ductility. Zirconia does not "bend" to dissipate stress; instead, once a critical crack grows, failure can be sudden.

For the clinician, the critical takeaway is that zirconia is often less forgiving of cumulative microdamage. Small surface flaws, minor prosthetic misfits, or repeated off-axis forces may not produce immediate symptoms but can promote slow crack growth over time (Zhang & Kelly, 2017). Consequently, zirconia treatment planning must emphasize load control and flaw avoidance, rather than assuming that "good primary stability" guarantees long-term mechanical safety.

This also influences how we interpret clinical success. With zirconia, early survival can look excellent while fatigue-related risks remain latent. Thus, "short-term success" should not be equated with "mechanical security," especially in posterior or parafunctio-nal contexts.

2.2 Hydrothermal Aging and Surface Integrity: Why It Is Clinically Relevant

Low-temperature degradation (hydrothermal aging) describes moisture-driven microstructural changes that can increase surface roughness and microcrack susceptibility over time (Grémillard et al., 2017). Clinically, the question is not whether aging exists, but whether it meaningfully shifts the fatigue threshold in real-world function. The current evidence suggests modern zirconia formulations are improved, yet long-term data (especially beyond a decade) remain limited (Rao, Kumaraswamy, Thomas, Boraiah, & Rana, 2023).

From a practical standpoint, this supports a cautious principle: zirconia should preferentially be used where occlusal forces are predictable and manageable and where prosthetic design can mi-nimize tensile stress concentration. Aging also reinforces the need for careful surface handling-scratches or microdamage from instrumentation, repeated try-ins, or improper adjustments can become initiation points for crack growth (Mussano, Genova, Munaron, Faga, & Carossa, 2016). Therefore, clinicians should treat zirconia implant components as "structural ceramics" in the operative field: avoid aggressive instrument contact, prevent contamination that necessitates repeated manipulation, and minimize any chairside modifications that could introduce defects.

2.3 One-Piece vs Two-Piece Zirconia Systems: A Mechanical–Clinical Trade-off

One-piece zirconia implants eliminate an implant–abutment mic-rogap and may provide favorable soft tissue outcomes. Mechanically, one-piece designs can also remove screw-joint complications. However, they impose prosthetic constraints: angulation corrections are limited, margin placement can be challenging, and the restoration must be designed around a fixed abutment geometry. In the presence of non-ideal implant positioning- a frequent reality in OMFS- these constraints can translate into unfavorable load paths.

Two-piece zirconia systems allow better prosthetic versatility but introduce an interface that may concentrate stresses depending on connection geometry (Bazal-Bonelli et al., 2020). Clinically, this can affect the risk profile in posterior regions, especially under oblique loading. The key clinical skill is not to "choose one-piece or two-piece" in isolation, but to match the system to the anatomic and prosthetic realities: if ideal placement and axial loading can be achieved, one-piece de-signs can be advantageous; when angulation correction is essential, two-piece systems may be more practical but require stricter biomechanical discipline.

3. Mechanical Behavior in the Mouth: Translating Mechanics into Clinical Reality

3.1 Axial vs Non-Axial Loading: The Central Clinical Problem

In clinical function, loads are rarely purely axial. Lateral excursions, cusp inclines, and parafunction generate non-axial forces that create bending moments (Andrade et al., 2023). For zirconia implants, this matters because bending increases tensile stresses at the cervical region—precisely where ceramics are most vulnerable. Clinically, this means that an occlusal scheme that is acceptable for titanium can be-come risky for zirconia if it produces consistent off-axis loading.

The practical translation is straightforward: zirconia implants demand occlusal simplification. This includes reducing cusp inclines, minimizing lateral interferences, and designing guidance in a way that limits lateral load transfer to implant restorations (İlhan, Ünsal, & Özmeriç, 2025). In posterior regions, narrow occlusal tables and controlled contacts become more than “good practice”—they become essential risk mitigation. Therefore, the clinician must evaluate the entire functional envelope: not only maximum bite force, but also chewing patterns, para-function, and the prosthetic occlusal architecture that will determine the directionality of load.

3.2 Implant Diameter, Length, and Crown-to-Implant Ratio: What Changes for Zirconia

Diameter is a dominant factor in mechanical safety. Increasing diameter reduces bending stress and improves fatigue resistance (Kohal & Dennison, 2020). In zirconia implant planning, diameter selection is often more critical than length when the limiting factor is bending and tensile stress rather than purely axial compressive load. Clinically, narrow-diameter zirconia implants should be approached with caution, especially in posterior sites or where off-axis loading is expected.

Crown-to-implant ratio and lever arms matter as well. A tall crown on a shorter implant increases bending moment at the crestal region (Kohal & Dennison, 2020). With titanium, some of this risk can be tolerated; with zirconia, the margin is narrower. This supports a clinical strategy favoring: (i) adequate implant diameter where possible, (ii) reduction of crown height space if feasible, and (iii) avoidance of canti-levered designs on zirconia implants unless the case is exceptionally favorable and well-controlled.

In OMFS cases with atrophy or reconstructed anatomy, where implant dimensions are constrained, these principles often push the clinician toward titanium or toward staged augmentation strategies if zirconia is strongly desired for esthetic reasons.

3.3 Primary Stability, Insertion Torque, and Osteotomy Strategy: Avoiding Iatrogenic Damage

Clinicians often focus on high insertion torque as a marker of success. With zirconia implants, excessive torque can be problematic if it induces microdamage at the implant surface or creates unfavorable stress concentrations (Arlucea et al., 2021). Unlike metal, zirconia does not tolerate surface flaws well. This does not imply that zirconia implants cannot achieve strong primary stability; rather, it emphasizes controlled surgical technique.

Clinically, the osteotomy should be accurate, with attention to avoiding forced seating or repeated insertion attempts. Irrigation and temperature control remain critical for bone vitality, but for zirconia the added emphasis is on preventing microchipping or scratches from handling. If the system requires a specific drilling protocol, adherence is essential; improvisation increases the risk of non-ideal seating and stress distribution.

The "surgical pearl" is to treat zirconia placement as a high-precision procedure: minimize reinsertion cycles, ensure correct angulation, and avoid any intraoperative adjustments that could damage the ceramic surface.

4. Failure Modes Explained in Clinical Language

4.1 Catastrophic Implant Fracture: How It Presents and Why It Happens

The feared complication is implant body fracture, which can occur abruptly (Sánchez-Pérez, Moya-Villaescusa, Jornet-García, & Gómez, 2010). Clinically, this may present as sudden mobility of the restoration, audible cracking, or immediate loss of function. The cervical region is typically the critical zone because it experiences the highest tensile stress under bending (Kapoor, Shah, Salem, & Quraishi, 2020). Importantly, patients may not report progressive symptoms beforehand, which makes preventive planning crucial.

The underlying mechanism is usually fatigue-driven: microcracks accumulate and propagate under repeated loading until a critical crack reaches unstable growth (Kruzic, Arsecularatne, Tanaka, Hoffman, & Cesar, 2018). Because zirconia is brittle, there is limited capacity for energy dissipation once the crack becomes critical. This is why meticulous occlusal management and avoidance of chronic off-axis forces are core to zirconia success.

From a clinician's standpoint, any case with high likelihood of non-axial loading—bruxism, steep guidance, cantilever neces-sity—should be considered high-risk for catastrophic zirconia failure.

4.2 Microdamage and Subcritical Crack Growth: The "Invisible" Risk

A second clinically relevant mechanism is subcritical crack growth that may remain invisible until failure. Chairside adjustments, polishing errors, or accidental surface scratches can serve as crack initiators (Ramos, Augusto, Alves, Kleverlaan, & Piva, 2023). Over time, cyclic loading drives crack propagation even if daily function seems normal. This makes prosthetic handling and finishing protocols central to long-term safety.

Clinically, this supports strict rules: avoid aggressive grinding, use appropriate polishing systems, minimize occlusal adjustment after delivery, and ensure that laboratory processing and clinical handling preserve surface integrity. Where adjustment is unavoidable, the clinician should consider whether the risk introduced is acceptable or whether an alternative restorative strategy is safer.

This also influences follow-up: clinicians should monitor occlu-sion changes over time, since wear of opposing dentition or resto-ration can shift load distribution and increase off-axis loading, potentially accelerating crack growth.

4.3 Prosthetic Triggers of Failure: Contacts, Cantilevers, and Mis-fit

Prosthetic misfit can induce preload stresses even before functional loading begins. With zirconia, these stresses can contribute to microdamage and accelerate fatigue (Zhang & Lawn, 2017). Therefore, passive fit and accurate occlusal design are not optional. Additionally, cantilevers increase bending moments and tensile stress at the cervical region, making them particularly unfavorable in zirconia implant restorations.

Clinical strategies to mitigate prosthetic risk include: narrowing the occlusal table, flattening cusp inclines, establishing light centric contacts with minimal excursive interferences, and using restorative designs that encourage axial loading (Andrade et al., 2023). In full-arch scenarios or long-span rehabilitations, the clinician should be especially cautious—titanium often remains the safer choice due to its greater mechanical tolerance.

5. Clinical Evidence: What We Can and Cannot Conclude Today

5.1 Survival vs Success: A Clinician's Interpretation Framework

Many clinical studies report high short-to-medium term survival for zirconia implants. However, "survival" (implant present in the mouth) is not equivalent to "success" (absence of biological and mechanical complications) (Padhye, Calciolari, Zuercher, Tagliaferri, & Donos, 2023). For zirconia, mechanical complicati-ons may emerge later because fatigue-related processes are time-dependent. Thus, an evidence-informed clinician should interpret excellent 1–5 year survival with cautious optimism rather than definitive assurance (Gunge, Ogino, Kihara, Tsukiyama, & Koyano, 2017).

Furthermore, study heterogeneity complicates generalization: different implant designs, surfaces, prosthetic protocols, and patient selection criteria yield outcomes that may not be comparable. Clinically, the most valid interpretation is that zirconia can work well in selected indications, but is not yet supported by the same breadth and duration of evidence as titanium. This evidence profile suggests a conservative adoption approach: prioritize zirconia where its advantages are clinically meaningful (esthetic zone, patient preference) and where mechanical risk can be minimized.

5.2 Biological Performance: Soft Tissue, Plaque, and Peri-Implant Health

Zirconia is often associated with favorable soft tissue behavior and reduced plaque accumulation compared to titanium (Kohal & Dennison, 2020). Clinically, this can translate into improved mucosal stability and less discoloration in thin biotypes. These biological advantages are particularly relevant in anterior esthetic cases and in patients with high esthetic expectations.

However, biological advantages do not automatically offset mechanical risk in high-load environments. The clinician must balance tissue-level benefits against the mechanical realities of the planned prosthesis. A biologically attractive material used in a mechanically unfavorable design may still fail catastrophically.

Therefore, clinicians should view zirconia's biological performance as a strong argument for carefully selected esthetic cases, not as a universal solution for all implant scenarios.

5.3 Long-Term Uncertainty: The Gap that Still Matters

A central limitation remains the relative scarcity of long-term (>10 years) data across diverse clinical contexts, especially in posterior regions and complex OMFS reconstructions (Ravidà et al., 2018). This matters because fatigue mechanisms and aging effects may become more clinically relevant over longer periods. In evidence-based practice, absence of long-term evidence should translate into conservative decision-making.

Clinicians should therefore disclose these uncertainties during informed consent, particularly when zirconia is chosen primarily for esthetic preference in cases with borderline biomechanics. Shared decision-making requires patients to understand that zirconia's long-term evidence base is still evolving.

6. Indication-Based Clinical Guidance for OMFS Practice

6.1 Situations Where Zirconia Is Clinically Rational

Zirconia implants are most rational when the primary clinical goal includes soft tissue esthetics and when biomechanical conditions are favorable. Typical examples include single-tooth replacement in the anterior region, adequate bone volume allowing appropriate implant diameter, and occlusion that can be designed to minimize lateral loads (Forna & Forna, 2019). In such cases, zirconia's optical and soft tissue ad-vantages can provide meaningful benefit.

Patients with strong preference for metal-free rehabilitation may also be candidates, provided biomechanical risk can be controlled. Importantly, the clinician should ensure that patient expectations do not override biomechanical feasibility; zirconia success depends on disciplined design and occlusal control (Daou, 2014).

In these scenarios, zirconia can be considered not as a compromise, but as an optimized choice aligned with specific clinical priorities.

6.2 Situations Where Zirconia Should Be Avoided or Used with High Caution

High-load posterior cases, severe bruxism, cantilever necessity, narrow ridge requiring narrow-diameter implants, and complex reconstructions with uncertain load paths represent high-risk contexts. In many of these, titanium remains the safer material due to its greater fatigue tolerance and long-term documentation (Steinherr, 2024).

In OMFS reconstructions (post-oncologic defects, irradiated bone, large graft reconstructions), the biomechanical environment is often unpredictable (Lommen et al., 2022). Until robust evidence supports zirconia performance in these contexts, clinicians should prioritize mechanical reliability and consider zirconia only within carefully controlled protocols or research settings. This guidance is not a dismissal of zirconia but a recognition that material choice must follow risk stratification rather than preference alone.

6.3 Practical Chairside Protocol: "Mechanical Safety Checklist"

A clinically useful approach is to apply a simple checklist before committing to zirconia: (i) Can I achieve adequate diameter? (ii) Can I avoid cantilever forces? (iii) Can I design occlusion to mi-nimize lateral loads? (iv) Is the patient free of significant parafunction or can it be managed effectively (e.g., night guard)? (v) Can I ensure minimal adjustment and excellent prosthetic fit? If multiple answers are "no," zirconia risk increases substantially (Koenig, Vanheusden, Goff, & Mainjot, 2013). To translate these biomechanical principles into a practical decision-making framework, a clinical mechanical risk scoring system is proposed in Table 1.

Table 1. Clinical Mechanical Risk Scoring System (Practical Chairside Tool)

Parameter	Low Risk (0)	Moderate Risk (1)	High Risk (2)
Implant region	Anterior	Premolar	Molar
Implant diameter	≥4.5 mm	4.0–4.5 mm	<4.0 mm
Crown height space	Normal	Moderately increased	Excessive

Occlusal scheme	Axial-dominant	Mixed	Lateral-dominant
Parafunction	None	Suspected	Confirmed
Prosthetic design	No cantilever	Minimal cantilever	Significant cantilever

*Total score interpretation: 0–3 for favorable for zirconia, 4–6 for the use with caution-strict biomechanical control required, ≥7 for zirconia not recommended-titanium preferred.

*This framework does not replace clinical judgment but provides a structured approach to integrating mechanical principles into everyday decision-making.

7. The Role of Biomechanical Modeling: Useful but Not Central

Finite element analysis and other modeling methods can support understanding of stress patterns and compare designs, but they should not replace clinical judgment. The clinical environment includes biological variability, patient behaviors, and prosthetic wear dynamics that are not fully captured by models (Broilo, Sartori, Mariano, Corso, & Shinkai, 2018). Therefore, clinicians should treat modeling as an adjunct for design thinking rather than as a determinant of case selection.

The most valuable outcome of modeling is often educational: it reinforces why cervical tensile stress is dangerous for zirconia and why prosthetic and occlusal design are decisive (Talmazov, Veilleux, Abdulmajeed, & Bencharit, 2020). The clinician's practical decision-making should remain anchored in mec-hanical principles and evidence quality rather than in model out-puts alone.

8. Future Directions with Direct Clinical Relevance

Progress in zirconia implantology is likely to come from several directions: improved material formulations resistant to aging, surface engineering that enhances osseointegration without compromising fatigue strength, and implant designs that reduce tensile stress concentration (Waghmare et al., 2024). Equally important is the emergence of standardized reporting frameworks for mechanical complications, which will improve the clinical interpretability of future studies.

Clinically, a major advance would be validated risk prediction approaches integrating patient factors (parafunction, occlusal scheme), anatomical factors (bone quality, crown height space), and prosthetic design variables (Wang et al., 2024). Such approaches could transform zirconia case selection from experience-based decisions into more quantifiable risk assessment. Until such tools are available, the clinician's best strategy is dis-ciplined application in favorable cases and transparent communication of uncertainty where evidence remains limited.

9. Conclusion: A Clinician's Bottom Line

Zirconia implants can provide meaningful esthetic and biological advantages, particularly in the anterior region and in patients with metal-free preferences. However, their mechanical behavior—high strength but brittle failure and limited fatigue tolerance—requires a distinct clinical mindset. Success with zirconia is de-termined less by "implant placement" alone and more by compre-hensive control of biomechanics through case selection, implant dimension choice, prosthetic architecture, and occlusal manage-ment.

In OMFS, where biomechanical challenges are frequent, zirconia should be used selectively and strategically. Titanium remains the safest default in high-load and complex reconstructive contexts. Zirconia should be considered when its specific advantages are clinically necessary and when mechanical risk can be minimized through disciplined planning and execution.

In practical terms, zirconia implantology is best regarded as a precision-based approach: when conditions are right and protocols are respected, outcomes can be excellent; when biomechanics are unfavorable or prosthetic discipline is compromised, mechanical failure can be abrupt and clinically costly. The clinician who understands these principles will be able to integrate zirconia implants safely into modern OMFS practice.

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CHAPTER 2

Complications and Risk Management in Third Molar Surgery

Özge Özdal Zincir[1]

1. Introduction

Surgical extraction of third molars is common in both oral and maxillofacial surgery and general dental practice. Despite generally favorable outcomes, complications may result in significant morbidity, prolonged recovery, or persistent functional impairment (Bouloux et al., 2007; Jerjes et al., 2006; Susarla & Dodson, 2004). Over the past two decades, advances in diagnostic imaging and a growing body of clinical evidence have demonstrated that third molar surgery should not be regarded as a purely routine intervention. Instead, it requires individualized assessment, risk stratification, patient counseling, and meticulous documentation (Peterson et al., 2014; Dodson, 2012).

Risk management in third molar surgery extends beyond technical execution and encompasses appropriate indication selection, radiological evaluation, informed consent, and structured postoperative follow-up, all of which are key determinants of both clinical outcomes and medico-legal liability (Givol et al., 2000; Levin, 2012).

2. Epidemiology and Indications

Third molars are the most frequently impacted teeth in the human dentition, with reported prevalence rates varying widely depending on population characteristics and diagnostic criteria (Quek et al., 2003). Indications for removal commonly include recurrent pericoronitis, dental caries, external root resorption, periodontal deterioration of the adjacent second molar, cystic or tumorous pathology, and selected orthodontic or prosthetic considerations (Marciani, 2007; Blondeau & Daniel, 2007).

Prophylactic removal of asymptomatic, pathology-free third molars remains controversial. Guideline-oriented approaches, such as those proposed by the National Institute for Health and Care Excellence (NICE, 2000), advise against routine extraction in the absence of disease. Consequently, the decision to remove third molars must be justified by an individualized risk–benefit assessment that considers patient age, predicted surgical difficulty, and the potential

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consequences of retention versus removal (Benediktsdottir, Wenzel, Petersen, & Hintze, 2004; Pogrel, 2012).

3. Framework for Preoperative Risk Assessment

Preoperative risk assessment is the cornerstone of complication prevention in third molar surgery. A practical framework stratifies risk across three interrelated domains: patient-related factors, tooth- and anatomy-related factors, and procedure- and surgeon-related factors (Baqain et al., 2008; Capuzzi, Montebugnoli, & Vaccaro, 1994).

A structured evaluation supports appropriate case selection, informed imaging decisions, effective patient counseling, and the implementation of risk-reducing strategies such as modified surgical techniques, coronectomy, or referral to experienced centers when indicated (Dodson, 2012; Levin, 2012).

4. Patient-Related Risk Factors

4.1 Age

Increasing age is consistently associated with higher rates of postoperative infection, delayed healing, alveolar osteitis, and neurosensory complications, particularly in deeply impacted mandibular third molars (Benediktsdottir et al., 2004; Krimmel & Reinert, 2000). Age-related increases in bone density and reduced regenerative capacity are thought to contribute to this elevated risk (Libersa et al., 2002).

4.2 Systemic Health and Medications

Systemic conditions significantly influence surgical risk and healing potential. Poorly controlled diabetes mellitus and immunosuppressive states are associated with increased postoperative infection rates and delayed wound healing (Little, Falace, Miller, & Rhodus, 2012; Lockhart, Brennan, & Sasser, 2003). Anticoagulant or antiplatelet therapy and inherited bleeding disorders necessitate individualized perioperative planning and, when appropriate, interdisciplinary management (Wahl, 1998).

4.3 Smoking, Oral Hygiene, and Compliance

Smoking is a well-established risk factor for alveolar osteitis and delayed healing due to nicotine-induced vasoconstriction and altered fibrinolytic activity (Sweet & Butler, 1979; Blum, 2002). Inadequate oral hygiene and poor compliance with postoperative instructions further increase the risk of infection and unfavorable outcomes (Levin, 2012).

5. Tooth- and Anatomy-Related Risk Factors

5.1 Depth, Type, and Angulation of Impaction

Surgical difficulty and complication risk increase with deeper impaction and unfavorable angulations such as horizontal or distoangular positions, which often require extensive bone removal and prolonged operative time (Pell & Gregory, 1933; Chiapasco, De Cicco, & Marrone, 1993).

5.2 Root Morphology and Mandibular Canal Proximity

Complex root morphology, including curvature or divergence, increases operative difficulty and the likelihood of root fracture (Sedaghatfar, August, & Dodson, 2005). The most critical determinant of inferior alveolar nerve injury is the spatial relationship between tooth roots and the mandibular canal (Rood & Shehab, 1990; Robinson, 1998).

6. Radiological Risk Stratification and Imaging Strategy

Panoramic radiography remains the first-line imaging modality for third molar assessment and identification of radiographic signs associated with increased nerve injury risk (Sedaghatfar et al., 2005; White & Pharoah, 2014). Cone-beam computed tomography (CBCT) provides three-dimensional assessment and is particularly valuable when panoramic findings suggest close proximity to the mandibular canal or when alternative treatment strategies such as coronectomy are considered (Tantanapornkul et al., 2007; AAOMS, 2016).

7. Intraoperative Complications: Prevention and Management

7.1 Neurosensory Injury

Inferior alveolar nerve injury is among the most serious complications of mandibular third molar surgery, with temporary sensory disturbances reported more frequently than permanent deficits (Renton, Hankins, Sproate, & McGurk, 2005; Jerjes et al., 2006). Lingual nerve injury, although less common, can significantly impair quality of life due to altered tongue sensation and taste (Hillerup, 2007; Valmaseda-Castellón, Berini-Aytés, & Gay-Escoda, 2000).

Risk reduction strategies include careful radiological assessment, conservative bone removal, avoidance of excessive force, minimal lingual flap manipulation, and selective use of coronectomy in high-risk cases (Monaco et al., 2004; Long et al., 2012).

7.2 Hemorrhage

Most intraoperative bleeding can be managed with local measures; however, severe hemorrhage may occur, particularly in medically compromised patients (Wahl, 1998; Carter & Goss, 2003).

7.3 Mandibular Fracture

Mandibular fracture associated with third molar surgery is rare but more likely in older patients with deeply impacted teeth and extensive bone removal (Krimmel & Reinert, 2000; Chrcanovic, 2014).

8. Postoperative Complications

Postoperative infection, alveolar osteitis, pain, swelling, trismus, delayed healing, and neurosensory disturbances remain the most frequently reported complications (Flynn, 2011; Marciani, 2011). Preventive strategies include atraumatic technique, smoking cessation counseling, appropriate analgesic and anti-inflammatory protocols, and careful postoperative monitoring (Moore, 2010; Dionne, Gordon, & Rowan, 2003).

9. Medico-Legal Risk Management

Third molar surgery is frequently associated with medico-legal claims, particularly in cases involving nerve injury or inadequate informed consent (Givol et al., 2000; Choi, Kim, & Jung, 2014). Clear documentation, individualized consent, and effective communication significantly reduce litigation risk.

10. Conclusion

Third molar surgery carries predictable risks that can be substantially reduced through structured preoperative assessment, selective imaging-based stratification, prevention-focused surgical technique, and standardized postoperative care. Equally important, meticulous informed consent and documentation protect both patient outcomes and medico-legal standing (Dodson, 2012; Givol et al., 2000).

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CHAPTER 3

Peri-Implantitis: Surgical Decision-Making Algorithms

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1. Introduction

Dental implants are widely regarded as a predictable and effective treatment modality for the replacement of missing teeth, offering high survival rates and favorable long-term outcomes. However, biological complications affecting peri-implant tissues remain a major clinical challenge and represent a growing concern in contemporary implant dentistry (Derks & Tomasi, 2015; Derks, Schaller, Håkansson, Wennström, Tomasi, & Berglundh, 2016; Karoussis et al., 2003; Lang & Berglundh, 2011).

Among these complications, peri-implantitis is of particular significance due to its progressive nature and potential to compromise implant survival if left untreated. Unlike peri-implant mucositis, which is confined to soft tissue inflammation and is largely reversible, peri-implantitis involves progressive bone loss and often necessitates active therapeutic intervention (Berglundh et al., 2018; Heitz-Mayfield & Salvi, 2018; Lindhe & Meyle, 2008; Schwarz et al., 2018).

The management of peri-implantitis is complex and multifactorial. Surgical treatment is frequently required in advanced cases; however, the selection of the most appropriate surgical approach remains controversial. Variability in defect morphology, implant surface characteristics, patient-related risk factors, and clinician experience contributes to inconsistent outcomes reported in the literature (Heitz-Mayfield & Mombelli, 2014; Renvert, Roos-Jansåker, & Claffey, 2008; Sanz & Chapple, 2012; Schwarz, Sahm, & Becker, 2011).

In recent years, algorithm-based decision-making models have gained increasing attention as a means of standardizing treatment planning while allowing individualized, patient-centered care. These models integrate clinical, radiographic, and biological parameters to guide clinicians toward the most appropriate surgical strategy (Chan, Lin, Suarez, Monje, & Wang, 2014; Chan et al., 2013; Monje et al., 2019).

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2. Definition, Diagnostic Criteria, and Classification of Peri-implantitis

2.1 Definition

Peri-implantitis is defined as a plaque-associated pathological condition occurring in tissues surrounding dental implants, characterized by inflammation of the peri-implant mucosa and progressive loss of supporting bone. This definition, established by the World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions, emphasizes both the inflammatory and destructive components of the disease (Berglundh et al., 2018; Lindhe & Meyle, 2008).

2.2 Diagnostic Criteria

Accurate diagnosis of peri-implantitis is essential for appropriate treatment planning. Diagnostic criteria typically include:

- Presence of bleeding and/or suppuration on probing
- Increased probing depth compared with previous examinations
- Radiographic evidence of bone loss beyond initial post-placement remodeling

These criteria are widely used in clinical practice and research (Berglundh et al., 2018; Heitz-Mayfield, 2008; Heitz-Mayfield & Mombelli, 2014). In the absence of baseline data, a probing depth ≥6 mm combined with radiographic bone loss ≥3 mm is commonly used as a diagnostic threshold (Berglundh et al., 2018; Schwarz et al., 2018).

2.3 Classification Systems

Several classification systems have been proposed to categorize peri-implantitis severity. These systems are generally based on:

- Clinical parameters (probing depth, bleeding, suppuration)
- Radiographic extent of bone loss relative to implant length
- Morphology of the peri-implant bone defect

From a surgical perspective, classification based on defect morphology is particularly relevant, as it directly influences treatment selection and prognosis (Froum & Rosen, 2012; Monje et al., 2019; Zitzmann & Berglundh, 2008).

3. Etiology and Pathogenesis

Peri-implantitis is a multifactorial disease resulting from the interaction between microbial biofilms and host immune response. While the microbial composition of peri-implantitis lesions resembles that of periodontitis, differences in peri-implant tissue anatomy and vascularization may contribute to more rapid disease progression (Derks & Berglundh, 2020; Heitz-Mayfield & Lang, 2010; Monje, Insua, & Wang, 2017).

The absence of periodontal ligament, reduced blood supply, and limited soft tissue attachment around implants may impair host defense mechanisms, rendering peri-implant tissues more susceptible to inflammatory destruction (Derks & Berglundh, 2020; Heitz-Mayfield & Lang, 2010; Monje, Insua, & Wang, 2017).

4. Risk Factors and Prognosis Assessment

4.1 Patient-Related Risk Factors

Patient-related factors play a critical role in both disease development and treatment outcomes. Well-established risk factors include:

- History of periodontitis
- Poor plaque control
- Smoking
- Uncontrolled diabetes mellitus
- Genetic susceptibility

Patients with a previous history of severe periodontitis exhibit significantly higher rates of peri-implantitis and reduced response to both non-surgical and surgical therapies (Karoussis et al., 2003; Renvert & Polyzois, 2015; Roccuzzo, Bonino, Dalmasso, & Aglietta, 2011; Serino & Turri, 2011).

4.2 Implant- and Prosthesis-Related Risk Factors

Implant surface roughness, design, and positioning influence plaque accumulation and disease susceptibility. Malpositioned implants, excessive buccal placement, and thin peri-implant bone are associated with increased risk of peri-implantitis (Monje et al., 2019; Romeo et al., 2005; Schwarz et al., 2006).

Prosthetic factors such as excess cement, non-cleansable emergence profiles, and inadequate interproximal access further contribute to disease development and progression (Monje et al., 2019; Romeo et al., 2005; Schwarz et al., 2006).

4.3 Prognosis Assessment

Before initiating surgical therapy, a realistic prognosis must be established. Key considerations include:

- Extent and pattern of bone loss
- Implant stability
- Defect configuration
- Patient compliance and motivation

Implants with advanced bone loss, unfavorable defect morphology, or poor patient compliance may have a questionable or hopeless prognosis, and explantation should be considered as part of the decision-making process (Karoussis et al., 2003; Monje, Insua, Rakic, & Schwarz, 2020; Roccuzzo et al., 2018).

5. Indications for Surgical Intervention

Non-surgical therapy alone is generally insufficient for the treatment of established peri-implantitis with significant bone loss. Surgical intervention is typically indicated when:

- Probing depths exceed 5–6 mm
- Progressive bone loss is evident
- Inflammation persists despite non-surgical measures

(Heitz-Mayfield & Mombelli, 2014; Renvert et al., 2008; Schwarz, Becker, & Renvert, 2018; Schwarz & Sculean, 2019)

The primary objectives of surgical therapy are to provide access for thorough decontamination, reduce peri-implant pocket depth, and, when possible, regenerate lost supporting tissues (Heitz-Mayfield & Mombelli, 2014; Renvert et al., 2008; Schwarz et al., 2018; Schwarz & Sculean, 2019).

6. Rationale for Algorithm-Based Surgical Decision-Making

Given the heterogeneity of peri-implantitis lesions, a standardized yet flexible decision-making framework is essential. Algorithm-based approaches allow clinicians to integrate multiple variables into a structured treatment plan while accommodating patient-specific factors (Chan et al., 2013; Chan et al., 2014; Monje et al., 2019).

Such algorithms typically incorporate:

- Defect morphology
- Implant surface characteristics
- Patient-related risk modifiers
- Expected long-term maintenance capability

7. Defect Morphology-Based Decision-Making Algorithms

Peri-implant bone defects may present as:

- Circumferential (contained intrabony) defects
- Horizontal bone loss
- Combined defects

(Froum & Rosen, 2012; Monje et al., 2019)

Contained intrabony defects are generally more favorable for regenerative therapy, whereas non-contained or horizontal defects are better suited to resective approaches (Froum & Rosen, 2012; Monje et al., 2019).

8. Implant Surface Characteristics and Surgical Strategy

Implant surface roughness significantly influences treatment outcomes. Moderately rough surfaces may respond more favorably to regenerative approaches if effective decontamination can be achieved, whereas highly rough or damaged surfaces may limit regenerative potential (Schwarz et al., 2006; Schwarz et al., 2018; Schwarz & Sculean, 2019).

Surface decontamination techniques should be selected based on surface characteristics, defect accessibility, and clinician experience (Schwarz et al., 2006; Schwarz et al., 2018; Schwarz & Sculean, 2019).

9. Patient-Related Modifiers in Surgical Decision-Making

Patient-related modifiers such as smoking, oral hygiene, systemic health, and compliance must be integrated into surgical algorithms. In high-risk patients, resective approaches may provide more predictable long-term stability compared with regenerative procedures (Monje, Catena, & Borgnakke, 2017; Renvert & Polyzois, 2015; Serino & Turri, 2011).

10. Resective Surgical Approaches

Resective surgery aims to eliminate peri-implant pockets by apical repositioning of soft tissues and recontouring of bone. This approach facilitates plaque control and long-term maintenance but does not restore lost bone (Renvert et al., 2008; Romeo et al., 2005; Schwarz et al., 2012; Serino & Turri, 2011).

Indications include horizontal bone loss, non-contained defects, and poor patient compliance (Renvert et al., 2008; Romeo et al., 2005; Schwarz et al., 2012; Serino & Turri, 2011).

11. Regenerative Surgical Approaches

Regenerative therapy seeks to restore lost peri-implant bone using bone grafts, barrier membranes, and biologic agents. Success is highly dependent on defect morphology, implant surface characteristics, and patient compliance (Roccuzzo et al., 2018; Roccuzzo, Stähli, Monje, & Sculean, 2021; Schwarz et al., 2011).

Evidence suggests that regenerative outcomes are most predictable in contained intrabony defects with good access and favorable patient factors (Roccuzzo et al., 2018; Roccuzzo et al., 2021; Schwarz et al., 2011).

12. Combined and Adjunctive Surgical Techniques

In selected cases, combined resective-regenerative approaches may be employed to optimize outcomes. Adjunctive measures such as soft tissue grafting may further enhance peri-implant health and facilitate maintenance (Jepsen et al., 2015; Schwarz et al., 2011; Schwarz et al., 2012).

13. Post-Surgical Maintenance and Supportive Therapy

Long-term success following peri-implantitis surgery is heavily dependent on supportive peri-implant therapy. Regular maintenance visits, professional plaque control, and reinforcement of oral hygiene practices are essential components of post-surgical care (Jepsen et al., 2015; Renvert & Giovannoli, 2021; Roccuzzo et al., 2011; Salvi & Zitzmann, 2014).

14. Long-Term Outcomes and Limitations of Surgical Therapy

While surgical therapy can arrest disease progression in many cases, complete resolution is not always achievable. Recurrence remains a concern, particularly in patients with persistent risk factors (Renvert & Giovannoli, 2021; Schwarz et al., 2017; Tomasi & Derks, 2022).

Clinicians must set realistic expectations and emphasize the importance of long-term maintenance (Renvert & Giovannoli, 2021; Schwarz et al., 2017; Tomasi & Derks, 2022).

15. Future Perspectives and Emerging Surgical Concepts

Emerging concepts in peri-implantitis management include novel surface decontamination technologies, biologic modifiers, host-modulation strategies, and digitally assisted surgical planning. Artificial intelligence-based risk assessment models may further refine algorithm-driven decision-making in the future (Renvert & Giovannoli, 2021; Schwarz et al., 2023; Schwarz et al., 2018).

16. Practical Clinical Recommendations

- Establish a precise diagnosis and realistic prognosis
- Use algorithm-based decision-making to guide surgical planning
- Select surgical approach based on defect morphology and patient risk profile
- Emphasize long-term maintenance as part of treatment planning

17. Conclusion

Peri-implantitis represents a complex and increasingly prevalent challenge in implant dentistry. Algorithm-based surgical decision-making provides a structured, evidence-based framework for managing this condition while allowing individualized patient care. Integration of clinical parameters, defect morphology, implant characteristics, and patient-related factors is essential for optimizing surgical outcomes and ensuring long-term implant stability (Schwarz et al., 2023; Zitzmann & Schwarz, 2014).

18. Microbiological and Host-Response Considerations in Surgical Decision-Making

The pathogenesis of peri-implantitis is driven by a complex interaction between microbial biofilms and the host immune response. Although the microbial profile of peri-implantitis lesions shares similarities with periodontitis, peri-implant tissues exhibit a more pronounced inflammatory response due to anatomical and vascular differences. The absence of periodontal ligament, reduced blood supply, and limited connective tissue attachment around implants may contribute to accelerated tissue breakdown once inflammation is established (Derks & Berglundh, 2020; Heitz-Mayfield & Lang, 2010; Monje, Insua, & Wang, 2017).

From a surgical decision-making perspective, the inflammatory burden and host response should be regarded as modifiers rather than primary determinants of treatment selection. Patients exhibiting aggressive inflammatory phenotypes, characterized by rapid bone loss and persistent suppuration, often demonstrate limited response to regenerative approaches, even in favorable defect morphologies. In such cases, resective strategies or implant removal may offer more predictable long-term stability (Monje & Schwarz, 2022; Monje et al., 2020).

Host-related immune dysregulation, including poorly controlled diabetes and smoking-induced vascular compromise, further reduces regenerative potential. Therefore, surgical algorithms must integrate not only defect morphology but also host-response characteristics to avoid biologically unrealistic treatment goals (Monje et al., 2017; Serino & Turri, 2011).

19. Detailed Surgical Decision-Making Algorithms: Step-by-Step Clinical Pathways

Algorithm-based surgical planning in peri-implantitis can be conceptualized as a sequential decision pathway rather than a rigid protocol. The first decision node involves assessment of implant stability and extent of bone loss. Implants demonstrating advanced circumferential bone loss exceeding 50% of implant length or mobility should be considered for explantation rather than surgical salvage (Monje et al., 2020; Schwarz & Jepsen, 2019).

In stable implants, the second decision node focuses on defect morphology. Contained intrabony defects with intact bony walls favor regenerative approaches, whereas non-contained or horizontal defects direct the clinician toward resective strategies. Implant surface accessibility represents a third critical node; inadequate access for surface decontamination significantly compromises regenerative outcomes (Chan et al., 2013; Chan et al., 2014; Monje et al., 2019).

Patient-related modifiers form the final decision layer. In patients with poor oral hygiene, smoking habits, or limited compliance, resective approaches provide superior long-term disease control despite inferior esthetic outcomes. Conversely, highly motivated patients with optimal plaque control may benefit from regenerative attempts even in moderately complex defects (Karoussis et al., 2003; Renvert & Polyzois, 2015; Serino & Turri, 2011).

20. Comparative Outcomes of Resective and Regenerative Surgical Approaches

The literature demonstrates substantial heterogeneity in reported outcomes following surgical treatment of peri-implantitis. Systematic reviews consistently indicate that both resective and regenerative approaches can reduce probing depth and bleeding on probing; however, true bone regeneration remains unpredictable (Renvert & Giovannoli, 2021; Roccuzzo et al., 2018; Roccuzzo et al., 2021).

Regenerative procedures show more favorable radiographic outcomes in contained defects but are associated with higher complication rates and technique sensitivity. Resective approaches, while incapable of restoring lost bone, provide more consistent pocket reduction and facilitate long-term maintenance. These findings support the concept that surgical success in peri-implantitis should be defined primarily by disease stability rather than radiographic bone gain (Monje & Schwarz, 2022; Roccuzzo et al., 2018; Schwarz et al., 2012).

21. When Surgery Fails: Re-intervention, Explantation, and Ethical Considerations

Failure of peri-implantitis surgery is not uncommon and should be anticipated during treatment planning. Recurrent inflammation, progressive bone loss, or persistent suppuration following surgical therapy necessitate reassessment of prognosis. Re-intervention may be considered in selected cases; however, repeated surgical attempts often yield diminishing returns (Monje et al., 2020; Schwarz et al., 2017).

Explantation should not be regarded as treatment failure but rather as a biologically sound decision when long-term stability cannot be achieved. Ethical clinical practice requires transparent communication with patients regarding the limitations of surgical therapy and the potential need for implant removal (Monje et al., 2020; Schwarz & Jepsen, 2019).

22. Expanded Conclusion

Peri-implantitis surgery requires a paradigm shift from technique-driven intervention to biologically informed decision-making. Algorithm-based surgical planning provides a structured framework that integrates defect morphology, implant characteristics, host factors, and long-term maintenance capacity. By prioritizing disease control and patient-centered outcomes over radiographic perfection, clinicians can achieve more predictable and ethically sound results in the management of peri-implantitis (Renvert & Giovannoli, 2021; Schwarz et al., 2023).

23. Implant Surface Decontamination: Evidence-Based Comparison of Surgical Adjuncts

Effective implant surface decontamination is a critical determinant of surgical success in peri-implantitis management. Regardless of whether a resective or regenerative approach is selected, inadequate biofilm removal from the implant surface significantly compromises treatment outcomes. However, no single decontamination method has demonstrated universal superiority, underscoring the need for evidence-based selection tailored to clinical conditions (Renvert & Giovannoli, 2021; Schwarz et al., 2018; Schwarz & Sculean, 2019).

23.1 Mechanical Decontamination

Mechanical methods, including titanium curettes, ultrasonic devices with non-metal tips, and rotating brushes, represent the foundation of implant surface decontamination. These techniques are widely available and cost-effective but are limited by access constraints and the risk of surface alteration. Studies indicate that while mechanical debridement effectively reduces microbial load, it rarely achieves complete biofilm removal on rough implant surfaces (Schwarz et al., 2018; Schwarz & Sculean, 2019).

Mechanical decontamination is most effective in resective surgical settings where implant surfaces are fully exposed and accessible. In regenerative procedures, however, incomplete surface access may limit its efficacy and jeopardize regenerative outcomes (Renvert et al., 2008; Romeo et al., 2005; Schwarz et al., 2012).

23.2 Chemical Decontamination

Chemical agents such as chlorhexidine, hydrogen peroxide, citric acid, and ethylenediaminetetraacetic acid (EDTA) have been employed as adjuncts to mechanical debridement. These agents may enhance bacterial reduction but demonstrate limited penetration into complex implant surface microstructures (Heitz-Mayfield & Mombelli, 2014; Schwarz & Sculean, 2019).

Evidence suggests that chemical agents alone are insufficient for predictable decontamination and should be regarded as supportive rather than primary modalities. Their use must be carefully controlled to avoid cytotoxic effects on surrounding tissues and regenerative materials (Heitz-Mayfield & Mombelli, 2014; Schwarz & Sculean, 2019).

23.3 Air-Abrasive Systems

Air-abrasive devices utilizing glycine or erythritol powders have gained popularity due to their ability to disrupt biofilms without significant surface damage. Clinical studies report favorable short-term reductions in inflammation and probing depth when air-abrasive systems are used as part of surgical therapy (Renvert & Giovannoli, 2021; Schwarz et al., 2023).

These systems appear particularly advantageous in regenerative procedures, where preservation of implant surface integrity is critical. However, long-term data regarding their impact on disease recurrence remain limited (Renvert & Giovannoli, 2021).

23.4 Laser-Assisted Decontamination

Various laser systems, including Er:YAG and diode lasers, have been investigated for implant surface decontamination. While lasers may offer antimicrobial effects and facilitate surface detoxification, results across studies remain inconsistent (Renvert & Giovannoli, 2021; Schwarz et al., 2018).

Laser use is highly operator-dependent and associated with a steep learning curve. Current evidence does not support routine laser use as a standalone decontamination method but suggests potential benefit as an adjunct in selected cases (Renvert & Giovannoli, 2021; Schwarz et al., 2018).

23.5 Clinical Implications

From an algorithmic perspective, implant surface decontamination should be selected based on:

- Implant surface roughness
- Accessibility of the implant surface
- Planned surgical approach (resective vs regenerative)
- Operator experience

Inadequate decontamination should be considered a relative contraindication to regenerative therapy (Renvert & Giovannoli, 2021; Schwarz et al., 2018; Schwarz & Sculean, 2019).

24. Comparative Outcomes of Resective and Regenerative Surgical Therapies: An Evidence-Based Synthesis

The comparative effectiveness of resective and regenerative surgical approaches in peri-implantitis has been extensively investigated; however, interpretation of outcomes is complicated by heterogeneity in study design, defect classification, and success criteria (Renvert & Giovannoli, 2021; Roccuzzo et al., 2018; Roccuzzo et al., 2021).

24.1 Resective Surgical Outcomes

Resective surgery consistently demonstrates reductions in probing depth and bleeding on probing, with outcomes that are relatively stable over time. Although radiographic bone regeneration is not achieved, disease stabilization and improved access for plaque control are common (Renvert et al., 2008; Romeo et al., 2005; Schwarz et al., 2012).

Long-term studies indicate that resective approaches yield predictable outcomes in patients with non-contained defects, horizontal bone loss, or limited compliance. Esthetic compromise remains a notable drawback, particularly in the anterior region (Schwarz et al., 2012; Schwarz et al., 2017).

24.2 Regenerative Surgical Outcomes

Regenerative therapy aims to restore lost peri-implant bone and improve implant support. Meta-analyses suggest that regenerative approaches can result in greater radiographic bone fill compared to resective surgery, particularly in contained intrabony defects (Roccuzzo et al., 2018; Roccuzzo et al., 2021).

However, regenerative outcomes are highly variable and sensitive to defect morphology, surface decontamination quality, and patient compliance. Complication rates, including membrane exposure and infection, are higher compared to resective therapy (Roccuzzo et al., 2018; Roccuzzo et al., 2021).

24.3 Redefining “Success” in Peri-implantitis Surgery

A critical limitation of the literature is the lack of standardized success criteria. Radiographic bone gain, often emphasized in regenerative studies, does not necessarily correlate with long-term disease stability (Monje & Schwarz, 2022).

From a clinical decision-making standpoint, success should be defined primarily by:

- Absence of bleeding and suppuration
- Stable probing depths
- No further radiographic bone loss

This paradigm supports algorithm-driven selection of surgical approaches based on predictability rather than maximal tissue reconstruction (Monje & Schwarz, 2022; Renvert & Giovannoli, 2021).

25. Combined and Staged Surgical Approaches

In selected cases, combined or staged surgical strategies may offer advantages over single-modality treatment. These approaches integrate elements of both resective and regenerative therapy to address complex defect configurations (Jepsen et al., 2015; Schwarz et al., 2011; Schwarz et al., 2012).

For example, partial resective correction of non-contained defect components followed by localized regenerative procedures may improve defect containment and enhance regenerative potential. Staged approaches may also allow reassessment of patient compliance and tissue response before undertaking regenerative therapy (Schwarz et al., 2011; Schwarz et al., 2012).

Such strategies require advanced surgical expertise and should be reserved for carefully selected cases (Schwarz et al., 2011; Schwarz et al., 2012).

26. Failure Patterns and Predictors of Surgical Breakdown

Understanding failure patterns is essential for refining surgical decision-making algorithms. Common predictors of surgical breakdown include:

- Persistent plaque accumulation
- Smoking relapse
- Inadequate maintenance therapy
- Extensive horizontal bone loss
- Poor soft tissue quality

(Renvert & Giovannoli, 2021; Schwarz et al., 2017; Tomasi & Derks, 2022)

Failure often manifests as recurrence of bleeding and suppuration within the first two years following surgery. Early identification of these signs should prompt reassessment of prognosis and consideration of alternative management strategies (Renvert & Giovannoli, 2021; Schwarz et al., 2017; Tomasi & Derks, 2022).

27. Explantation as a Treatment Endpoint

Explantation represents a definitive solution for implants with advanced peri-implantitis and poor prognosis. Importantly, implant removal should be viewed not as a therapeutic failure but as a biologically rational decision aimed at preserving overall oral health (Monje et al., 2020; Schwarz & Jepsen, 2019).

Decision-making algorithms should explicitly include explantation as a valid endpoint when:

- Bone loss exceeds 50–60% of implant length
- Implant mobility is present
- Repeated surgical interventions have failed
- Patient-related risk factors cannot be adequately controlled

(Monje et al., 2020; Schwarz & Jepsen, 2019)

Transparent discussion of explantation during informed consent is essential to ethical clinical practice (Monje et al., 2020; Schwarz & Jepsen, 2019).

28. Long-Term Maintenance as the Determinant of Surgical Success

Surgical intervention alone cannot ensure long-term disease control in peri-implantitis. Supportive peri-implant therapy represents the most critical determinant of long-term success (Jepsen et al., 2015; Renvert & Giovannoli, 2021; Roccuzzo et al., 2011; Salvi & Zitzmann, 2014).

Maintenance protocols should be individualized based on risk assessment and include:

- Regular professional plaque removal
- Monitoring of probing depths and bleeding
- Radiographic evaluation at defined intervals
- Reinforcement of patient oral hygiene

(Jepsen et al., 2015; Renvert & Giovannoli, 2021; Roccuzzo et al., 2011; Salvi & Zitzmann, 2014)

Failure to establish effective maintenance dramatically increases the risk of disease recurrence, regardless of surgical technique (Jepsen et al., 2015; Renvert & Giovannoli, 2021; Roccuzzo et al., 2011; Salvi & Zitzmann, 2014).

29. Emerging Surgical Concepts and Future Directions

Future directions in peri-implantitis surgery are increasingly focused on personalization and biologically driven decision-making. Advances in digital diagnostics, three-dimensional defect analysis, and artificial intelligence-based risk modeling hold promise for refining algorithm-based treatment planning (Renvert & Giovannoli, 2021; Schwarz et al., 2023).

Novel biologic agents, host-modulation strategies, and surface modification technologies may further enhance surgical outcomes. However, long-term evidence remains limited, and cautious integration into clinical practice is warranted (Renvert & Giovannoli, 2021; Schwarz et al., 2023).

30. Final Integrated Clinical Algorithm (Textual Synthesis)

Peri-implantitis surgical decision-making should proceed through the following sequential framework (Chan et al., 2013; Chan et al., 2014; Monje et al., 2019):

1. Confirm diagnosis and assess implant stability
2. Evaluate extent and morphology of bone loss
3. Assess patient-related risk factors and compliance
4. Determine feasibility of effective surface decontamination
5. Select resective, regenerative, combined, or explantation strategy
6. Establish long-term maintenance protocol

31. Expanded Final Conclusion

Peri-implantitis represents a multifaceted clinical challenge requiring more than technical surgical proficiency. Algorithm-based surgical decision-making offers a structured framework that integrates biological principles, defect morphology, implant characteristics, and patient-related factors into coherent treatment pathways (Renvert & Giovannoli, 2021; Schwarz et al., 2023).

By prioritizing disease stability, realistic prognostic assessment, and long-term maintenance over aggressive reconstruction, clinicians can achieve more predictable and ethically sound outcomes. As implant dentistry continues to evolve, structured decision-making algorithms will play an increasingly central role in the surgical management of peri-implantitis (Renvert & Giovannoli, 2021; Schwarz et al., 2023).

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CHAPTER 4

Complicatıons in Orthognathic Surgery and Contemporary Management Strategies

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1.INTRODUCTION

Orthognathic surgery is an advanced surgical procedure that focuses on the surgical repositioning of the jaws to treat congenital or acquired dentofacial deformities, aiming to correct functional disorders and improve facial aesthetics. Indications for orthognathic surgery include impaired mastication and phonation, chronic maxillomandibular pain, limited mouth opening, anterior open bite, facial imbalance and disproportion, as well as three-dimensional discrepancies between the jaws and the facial skeleton. In addition, certain techniques used in orthognathic surgery may also be applied in the reconstruction of maxillofacial defects following tumor resection and in the treatment of patients with obstructive sleep apnea syndrome. (Panula, Finne, & Oikarinen, 2001; Sousa & Turrini, 2012)

Orthognathic surgery, which aims to reposition the jaws, has been shown to significantly improve facial balance and proportion. Orthognathic surgery enables the achievement of functional and aesthetic objectives by effectively addressing both skeletal and soft tissue components. However, the benefits of orthognathic surgery extend beyond mere functional and aesthetic improvements; it has also been demonstrated to positively impact patients' psychological well-being and social lives. (S.-G. Kim & Park, 2007; Naran, Steinbacher, & Taylor, 2018)

As with any surgical procedure, various complications have been reported during and after orthognathic surgery. These complications may range from clinically insignificant and transient findings to severe conditions that can result in permanent functional impairment and markedly diminish the patient's quality of life. However, the vast majority of these complications can be effectively managed through appropriate therapeutic approaches and a thorough understanding of their underlying causes. (Y.-K. Kim, 2017)

As with all surgical procedures, orthognathic surgery is associated with certain risks and complications, in addition to functional and aesthetic benefits. The

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nature of these complications is variable and influenced by factors such as patient characteristics, surgical technique, perioperative management, and the recovery process. These complications have the potential to affect clinical outcomes in both the short and long term. Therefore, a comprehensive assessment of the complications associated with orthognathic surgery is crucial for both ensuring patient safety and enhancing surgical success. This section addresses common complications associated with orthognathic surgery and the current approaches to their management.

2.CLASSIFICATION OF COMPLICATIONS

Complications in orthognathic surgery can be classified in various ways. This classification is typically based on etiology, that is, the affected system and the time of onset. A thorough understanding of classification is important because the accurate identification and systematic evaluation of complications enable early diagnosis and the determination of an appropriate treatment approach. Furthermore, it plays a pivotal role in the process of surgical planning, risk anticipation, and the accurate provision of patient information.

From an etiological perspective, complications can be categorized as neurological, vascular, skeletal, infectious, and soft tissue-related. Based on the timing of their occurrence, complications are classified as intraoperative or postoperative. The following factors have been identified as risk factors in the development of these complications: gender, the presence of impacted third molar teeth in the surgical area, the duration of the operation, the surgeon's experience, the type of maxillomandibular deformity, and whether the surgery is performed on a single jaw or both jaws. (Zaroni et al., 2019)

Table 1. Complications of Orthognathic Surgery According to Timing

TIME	COMPLICATIONS
INTRAOPERATIVE	1. Bleeding 2. Bad Split 3. Nerve Injury 4. Dental Injury 5. Soft Tissue Injury 6. Instrument Breakage or Aspiration 7. Vomerosphenoidal Joint Separation 8. Trigeminocardiac Reflex
POSTOPERATIVE	1. Infection 2. Malocclusion 3. Relapse 4. Nasolacrimal Duct Obstruction and Epiphora 5. Condylar Resorption and TME Problems 6. Changes in Nasal Morphology 7. Sinus Problems 8. Avascular Necrosis 9. Auriculotemporal Syndrome 10. Complications Related to Fixation Materials 11. Psychological Changes 12. Neuropathic Pain 13. Nonunion of the Osteotomy Line 14. Respiratory System Complications 15. Nausea and Vomiting 16. Pseudoaneurysm

Table 2. Complications Depending on the Affected System

SYSTEMS	COMPLICATIONS
Neurological	N. alveolaris inferior; N. mentalis; N. infraorbitalis; N. lingualis; N. facialis hasarı; Paresthesia; Hypoesthesia; Anesthesia; Dysesthesia; Neuropathic pain
Vascular	Intraoperative bleeding; Postoperative bleeding; Hematoma; Pseudoaneurysm; Arteriovenous fistula
Infectious	Wound infection; Osteomyelitis; Plaque/screw infection; Sinusitis
Bone and Fixation	Bad split; Osteotomy line failure; Bone resorption; Plate/screw fracture; Screw loosening
Dental / Periodontal	Tooth root damage; Pulp necrosis; Tooth mobility; Periodontal pocket; Gingival recession; Tooth loss
TMJ	TMJ pain; Disc displacement; Restricted movement; Clicking; Crepitation; Ankylosis
Respiratory System	Upper airway obstruction; Dyspnea; Aspiration; Obstructive sleep apnea
Aesthetic / Soft Tissue	Asymmetry; Widening of the nasal base; Nasolabial angle change; Lip position disorder; Soft tissue sagging
Functional	Chewing disorder; Speech disorder; Difficulty swallowing; Reduced mouth opening.
Psychological	Depression; Anxiety; Social adjustment problems

3. INTRAOPERATIVE COMPLICATIONS AND CURRENT APPROACHES

3.1.BLEEDING

In orthognathic surgery, bleeding is considered a significant complication, occurring with a prevalence of approximately 0.2–2.2%, and it can be fatal depending on its severity. The main anatomical structures that can cause bleeding include the a.v.maxillaris, pterygoid venous plexus, a.v.alveolaris inferior, a.v.retromandibularis, a.palatina descendens, and a.facialis. The pterygoid venous plexus is clinically significant because it may contribute to delayed hemorrhage.

Intraoperative bleeding may occur during dissection, tissue retraction, or separation of soft tissues, and it may also result from inadequate hemostasis following surgical incision. In particular, the separation of the pterygoid plates from the maxilla and the mobilization of the maxilla should be performed with utmost care. Moreover, inadequate hemostasis following the incision may result in intraoperative bleeding.

Several approaches may be employed to control bleeding, including the application of pressure, the use of bone wax or absorbable hemostatic materials, tamponade with gauze impregnated with thrombin or epinephrine, and electrocauterization. Vessel ligation may be performed to prevent secondary bleeding in major vascular injuries. Severe arterial bleeding may require a blood transfusion. Intense arterial bleeding, particularly evident in LeFort I osteotomies, may present as nosebleeds in the postoperative period.

Hypotensive general anesthesia, head elevation, and the use of vasoconstrictor agents are recommended to prevent bleeding. In the LeFort I procedure, it is important to preserve the palatine artery at an appropriate angle to ensure adequate blood perfusion of the maxilla, as this artery has been reported to be the most common source of postoperative bleeding. (Joachim et al., 2022; Lanigan, Hey, & West, 1990; Sousa & Turrini, 2012)

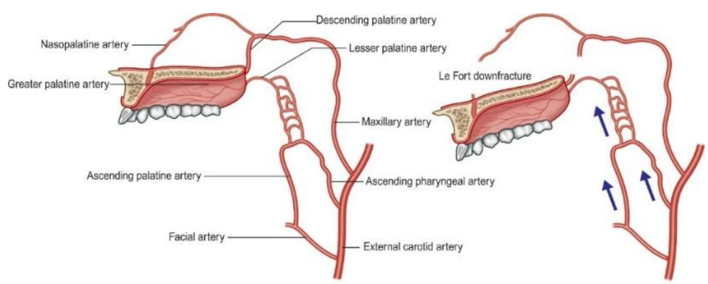

Figure 1. The arterial supply of the maxilla and the relationship of palatal vascular structures during Le Fort I downfracture. (Smartt Jr, 2013)

3.2.NERVE INJURY

Following osteotomies performed during orthognathic surgery, neurosensory alterations of varying severity may occur. While these alterations may fully resolve in some cases, resulting in complete recovery, others may experience only partial improvement, which typically does not significantly impact daily function, whereas permanent neurosensory deficits may occur in certain patients. It has been reported that recovery is more common in younger patients, whereas the likelihood of reversal of sensory impairment decreases with advancing age.

During orthognathic surgery, the jawbone lies in close proximity to the third branch of the trigeminal nerve, thereby increasing the risk of nerve injury, particularly during mandibular sagittal split osteotomy. It should be noted that during this procedure, the inferior alveolar nerve is at risk, particularly during the stages of separation and fixation. Indeed, the most common nerve injury in orthognathic surgery involves this nerve. Traction injuries may occur in this nerve during the split phase, and excessive mandibular advancement may increase this risk. Although lingual nerve injuries are rare during the placement of bicortical screws, facial nerve damage may also occur in cases of excessive mandibular advancement. Inferior alveolar nerve injuries typically manifest clinically as varying degrees of sensory loss in the lower lip. In maxillary osteotomies, the infraorbital nerve must be preserved, and careful attention should be paid to the palatal neurovascular structures.

The choice of treatment for nerve injuries depends on the type and severity of the damage. Conservative approaches include the administration of corticosteroids, vitamin B supplements, and low-dose laser therapy, whereas surgical options involve nerve exploration, neurorrhaphy, and decompression. The use of platelet-rich plasma (PRP) in regenerative therapies represents a viable alternative. However, the effectiveness of these treatments is contingent upon the extent of nerve damage, and satisfactory outcomes may be limited in certain cases. Therefore, the primary focus should be on the prevention of nerve-related complications rather than on treatment. Modifications in surgical techniques, careful management of the mandibular nerve canal, and proper positioning of fixation screws have been demonstrated to be effective in minimizing the risk of nerve injuries. (D'Agostino, Trevisiol, Gugole, Bondí, & Nocini, 2010; Jääskeläinen, Peltola, & Lehtinen, 1996; Joachim et al., 2022; McLeod & Bowe, 2016; Robl, Farrell, & Tucker, 2014; Zhao, Zhao, Xu, Wang, & Xiao, 2025)

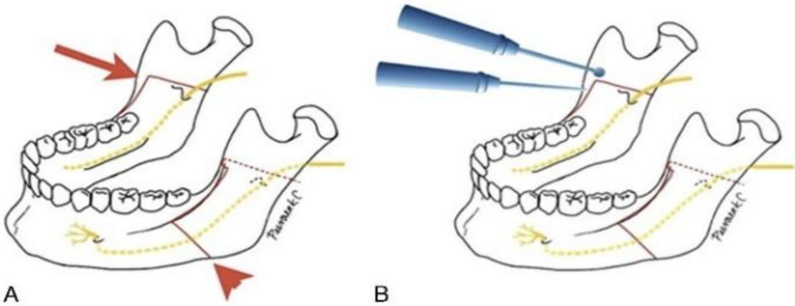

Figure 2. Anatomy of the Mandible and Inferior Alveolar Nerve in relation to the osteotomy line. A, corticotomy lines (red line). B, instruments used in corticotomy (Lindeman and spherical bur). (Chortrakarnkij et al., 2017)

3.3.BAD SPLIT

Fractures of a suboptimal nature are most frequently observed in sagittal split osteotomies. The most prevalent type of adverse fracture is buccal cortical plate fractures of the proximal segment. Although these fractures can occur in various shapes and degrees of severity, they can generally be effectively managed by fixing or removing the fractured segment. Lingual fractures of the distal segment represent the second most prevalent type. The need for fixation during surgery is contingent upon the orientation of the fracture. However, in certain cases, these fractures can be managed without fixation. The most serious complication involves fractures of the condyle. Such fractures may lead to challenging postoperative complications, including delayed healing, functional impairment, and damage to the neurovascular bundle. Therefore, during bilateral sagittal split osteotomy, it is essential to ensure that bone cuts are thoroughly completed in both the horizontal and vertical directions to achieve adequate separation.

Unfavorable fractures during Le Fort I osteotomy may extend to the pterygoid plates, pterygomaxillary fossa, sphenoid bone, and even the cranial base. The maxillary tuberosity and hard palate may also be affected in this process. In addition, although rare, fractures involving the anterior segment of the maxilla have been reported. During Le Fort I osteotomy, it is crucial to ensure that all osteotomy cuts are thoroughly and carefully completed before proceeding to the down-fracture stage. Separation of the pterygomaxillary junction is regarded as one of the most critical steps in Le Fort I osteotomy, as it is located posterior to the maxillary tuberosity and performed without direct visual control. Furthermore, the presence of numerous important anatomical structures adjacent to the pterygomaxillary junction increases the potential risk of complications at this stage.

It is recommended that impacted third molars be extracted at least 6–9 months prior to sagittal split osteotomy. The primary rationale is that the bone in the lingual region of the distal segment is naturally thin, and the presence of impacted teeth further compromises the structural integrity of this area. The presence of impacted third molars during surgery has been documented as a significant factor contributing to the risk of unwanted separation. In cases where the mandible is anatomically thin or exhibits structural irregularities, impacted third molars may further reduce bone thickness in the region, thereby increasing the likelihood of fracture. Furthermore, the insertion of screws into areas of thin bone may result in inadequate fixation, thereby limiting optimal plate or screw placement. Consequently, the decision to extract impacted third molars should be based on factors such as the surgeon's experience, the tooth's position within the mandible, angulation, relative height, root morphology, and its anatomical relationship with the neurovascular bundle. However, some studies have advocated for the extraction of impacted third molars during sagittal split osteotomy. The existing literature emphasizes that aggressive bone removal, particularly of the lingual cortex, may lead to unfavorable mandibular fractures during subsequent sagittal split osteotomy.

The management of fractures depends on both the type of fracture and its anatomical location. The initial step in evaluating malunions is a careful assessment of the shape, location, and size of the fracture fragments. Rigid fixation with plates and screws is recommended for large or severe fractures. Maintaining the correct position of the condyle within the glenoid fossa during the release of intermaxillary fixation (IMF) is of critical importance. In cases where intraoperative fixation is insufficient, permanent IMF may be applied for approximately six weeks. Patient age is a significant risk factor for impaired fracture healing, with this complication being more prevalent in older patients. If a malunion resulting from sagittal split osteotomy is not managed appropriately, it may lead to serious complications, including infection, sequestration of bone fragments, delayed bone healing, and pseudoarthrosis. Additionally, postoperative mandibular instability or dysfunction may occur, potentially resulting in temporomandibular joint (TMJ) dysfunction. The most significant concern with malunions is impaired bone union, which may increase the risk of sequestration and lead to higher infection rates. Anatomical factors, such as a thin mandibular ramus, a high mandibular lingula, or the presence of third molars, as well as the surgeon's inexperience or negligence, may contribute to the formation of jaw separations. In conclusion, it should be noted that excessive advancement in sagittal split osteotomy may necessitate additional fixation and the application of IMF. (Chrcanovic & Freire-Maia, 2012; Peltoperä, Kotaniemi, Suojanen, & Stoor, 2024; Veras, Kriwalsky, Hoffmann, Maurer, & Schubert, 2008)

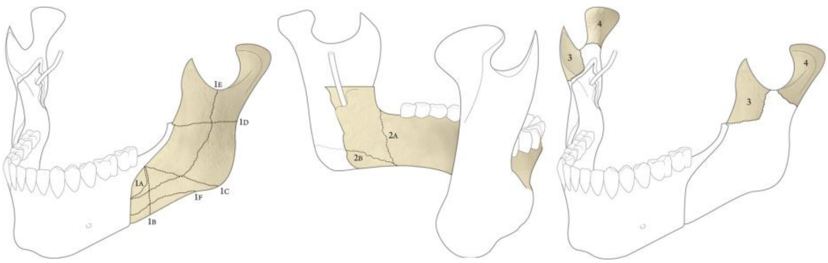

Figure 3. Types of malunions reported in the literature (1971-2015). Type 1: Proximal Segment (buccal) fractures. (Type 1A: Small Anterior, Type 1B: Vertical, Type 1C: Angular, Type 1D: Horizontal, Type 1E: Oblique, Type 1F: Lower Edge) (Steenen & Becking, 2016)

3.4.DENTAL INJURY

These complications are most frequently associated with maxillary segmentation but may also occur in mandibular segmental osteotomies. Careful preoperative planning is essential to minimize the risk of iatrogenic dental injury, and the use of appropriate osteotomy blades is critical in protecting dental tissues. Following orthognathic surgery, patients may experience complications such as dental devitalization, periodontal problems, endodontic issues, or tooth loss, particularly in teeth adjacent to the osteotomy line. Interdental osteotomies performed without adequate care can result in tooth loss; therefore, a minimum distance of 3 mm between adjacent teeth should be maintained, and orthodontic planning should ensure sufficient interdental space. To prevent nerve injury, subapical osteotomies should be performed at least 5 mm away from the tooth root. (de Santana Santos, Albuquerque, Santos, & Laureano Filho, 2012; Olate, Sigua, Asprino, & de Moraes, 2018)

3.5.VOMEROSPHENOIDAL JOINT SEPARATION

Vomero-sphenoidal joint separation may occur during maxillary osteotomy as a result of improper use of the septal osteotome. Contact of the osteotome with the vomer can produce resistance, and mobility of the vomer after down-fracture indicates that the maxilla should remain in its position. Excessive resection may cause mucosal tearing and increase the risk of bleeding. Complete removal of the vomer does not result in significant functional loss, and exposure of the sphenoid sinus has not been reported to produce adverse outcomes. Although the vomer contributes to posterior choanal integrity, it is not essential for maintaining airway patency and is often intentionally fractured during septoplasty. Inadequate inferior cuts during maxillary osteotomy may lead to unintended vomer separation, potentially traumatizing the sphenopalatine arteries and causing postoperative bleeding. Disruption of the vomer–cartilage junction may result in septal perforation, although functional impairment is generally minimal. (Y.-K. Kim, 2017; Smith & Heggie, 1995)

3.6.TRIGEMINOCADIAC REFLEX

The trigeminocardiac reflex (TCR) is a physiological response characterised by bradycardia, hypotension, and asystole, triggered during maxillofacial surgery by stimulation of trigeminal nerve branches. It develops via an afferent pathway between the trigeminal nucleus and the vagus motor nucleus, resulting in decreased heart rate and blood pressure. Orthognathic procedures such as Le Fort osteotomies, bilateral sagittal split osteotomies (BSSO), and genioplasty may elicit TCR through mechanical stimulation of the maxillary and mandibular branches. Its occurrence depends on the type and intensity of surgical stimulus, anaesthesia depth, and patient-specific factors. Clinically, transient bradycardia and asystole are the most common manifestations, with maxillary mobilisation after Le Fort I osteotomy being the primary trigger. Management involves immediate cessation of surgical manipulation, and in severe cases, administration of anticholinergic agents such as atropine or glycopyrrolate. The Gow-Gates mandibular nerve block may reduce TCR incidence in BSSO, though the risk cannot be completely eliminated. (Ortiz-Peces et al., 2025; Yusuf et al., 2026)

4.POSTOPERATIVE COMPLICATIONS AND CURRENT APPROACHES

4.1.INFECTION

In general, the prevalence of infection following osteotomies of the maxilla and mandible is reported to be low. Factors influencing these rates include patient age, duration of surgery, type of orthognathic procedure performed, and the use of prophylactic antibiotics.

The use of antibiotics prior to surgery has been shown to be effective in preventing postoperative infections; however, due to the limited prevalence of prophylactic use and the scarcity of published reports on this topic, such complications are considered rare. The performance of orthognathic surgery under general anesthesia and in highly sterile conditions further contributes to the already low risk of infection. Consequently, the necessity of prophylactic antibiotic administration in these procedures, where the infection risk is relatively low, remains controversial.

Care should be taken to ensure that the antibiotic dose administered postoperatively is adequate, as insufficient dosing may compromise infection prevention. Among the microorganisms most commonly encountered in oral and maxillofacial surgical procedures are streptococci, anaerobic Gram-positive cocci, and anaerobic Gram-negative bacilli. Therefore, the selected antibiotic should be effective against these microorganisms, which have the highest potential to cause infection. (Chow, Singh, Chiu, & Samman, 2007; Spaey et al., 2005; Zumla, 2010)

4.2.RELAPSE

Relapse is defined as the partial or complete loss of skeletal or dental corrections achieved during treatment. Factors associated with relapse include the direction and magnitude of bone rotation, asymmetry, postoperative changes in tooth positions, variations in condylar position, alterations in ramus inclination, changes in the mandibular plane, the type of fixation used (rigid or non-rigid), ill-fitting final splints, and inaccurate orthodontic procedures performed prior to surgery.

Condylar morphological abnormalities, muscle tension resulting from excessive surgical movements, and incorrect placement of the condyles in the glenoid fossa during surgery are among the main causes of short-term relapse. Long-term relapse, on the other hand, is associated with progressive morphological changes in the condyles, resorption and adaptation processes, and ongoing skeletal growth. Relapse is a dynamic and continuous process that arises from the contribution of various factors effective in the short and long term.

One of the most significant problems in patients undergoing orthognathic surgery is postoperative skeletal relapse. However, with the introduction of rigid internal fixation techniques, postoperative stability has increased and a significant reduction in relapse rates has been achieved. (Eggensperger, Smolka, Luder, & Iizuka, 2006; Inchingolo et al., 2023; Joachim et al., 2022)

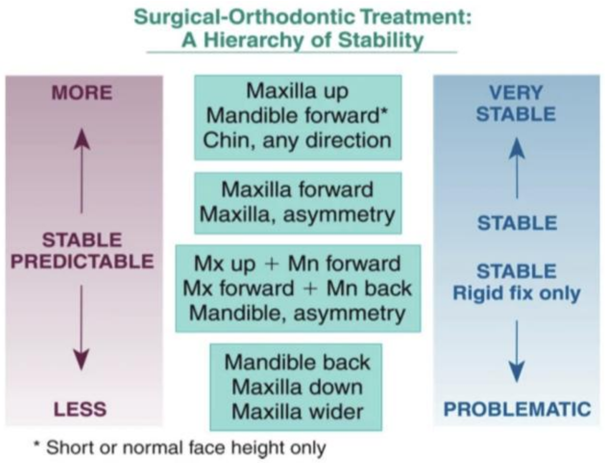

Figure 4. Hierarchy of stability and predictability with rigid fixation in orthognathic surgery (Proffit, Turvey, & Phillips, 2007)

4.3. MALOCCLUSION

Malocclusion is defined as a deviation from the planned occlusion that may require intermaxillary elastics or postoperative orthodontic treatment. Its development is influenced by factors such as the severity of the dentofacial deformity, surgical complexity, fixation technique, surgeon experience, failures in plate or screw fixation, patient non-compliance, improper mandibular condyle positioning, relapse after maxillary expansion, orthodontic relapse, and condylar resorption. Patients with ongoing growth remain at risk for later malocclusion. Depending on severity, these conditions can often be managed with orthodontic treatment, although revision surgery may be required in severe cases. (Zaroni et al., 2019)

4.4 NONUNION OF THE OSTEOTOMY LINE

Delayed or failed healing of the hard and soft tissues at the osteotomy site may result in delayed union or nonunion. The risk of non-union increases in cases of non-rigid fixation where there is significant displacement of the bone segment. Early occlusal contact after surgery and improperly prepared splints can negatively affect the stabilisation and healing of bone segments. Furthermore, delayed union or nonunion is more likely to occur in patients with systemic diseases and impaired wound healing. (Y.-K. Kim, 2017)

4.5. AVASCULAR NECROSIS

Although the etiology of necrosis has not been definitively elucidated, local ischemia resulting from excessive soft tissue ablation, together with concomitant hematoma formation, is considered among the primary contributing factors. Avascular necrosis of the maxilla is a rare complication that may range from minor soft tissue injury to complete maxillary loss. Following Le Fort I osteotomy, it has been demonstrated that the maxillary segment is predominantly supplied by the a.palatina ascendens, a.palatina descendens and a.pharyngya ascendens, with a rich anastomotic network formed by the alveolar branches of the internal maxillary artery.

Blood flow to the maxilla may decrease significantly in the early postoperative period due to factors such as hypotensive anaesthesia, osteotomies and compression of the vessels supplying the maxilla intraoperative. However, as the maxilla is a highly vascularised and well-perfused bone, avascular necrosis following Le Fort I osteotomy is a rare complication, with an incidence rate below 1%. Although ligation of the descending palatine artery impairs the perfusion of the osteotomy segment, it is often preferred because it facilitates surgical mobilisation and reduces the risk of postoperative bleeding. However, ligating this artery during surgery may lead to maxillary hypoperfusion, increasing the risk of avascular necrosis. The artery may also be damaged during maxillary mobilisation, particularly in cases of advanced maxillary protrusion.

Preservation of soft-tissue and muscle attachments is crucial in preventing segmental devitalisation during mandibular osteotomies. Proximal segment necrosis is most commonly observed following intraoral vertical subcondylar osteotomy, and preservation of a portion of the medial pterygoid muscle attachment on the posteromedial aspect of the segment is recommended. Excessive removal of periosteal attachments may compromise blood flow to the segment, potentially resulting in necrosis. Therefore, during mandibular surgery, it is essential to preserve the soft tissue and muscular attachments that sustain the vascular supply to the bone.

Inadequate monitoring of maxillary perfusion in the early postoperative period may lead to failure to detect early signs of avascular necrosis, resulting in serious clinical consequences. The main risk factors associated with the aetiology of avascular necrosis include maxillary surgical procedures involving more than two bone segments; advancement of segments greater than 10 mm; excessive heat generation due to inadequate irrigation during osteotomies; insufficient segment stabilisation; pressure from palatal plates; systemic diseases affecting the vascular system; conditions that impair wound healing; smoking; and prolonged hypotensive anaesthesia. In the treatment of bone segment necrosis, surgical resection of necrotic tissue may be required in combination with intravenous administration of third-generation cephalosporins and metronidazole. (Ettinger, Nathan, Guerrero, Salinas, & Arce, 2020; Y.-K. Kim, 2017; Vitkos, Kounatidou, Agoropoulos, & Kyrgidis, 2023)

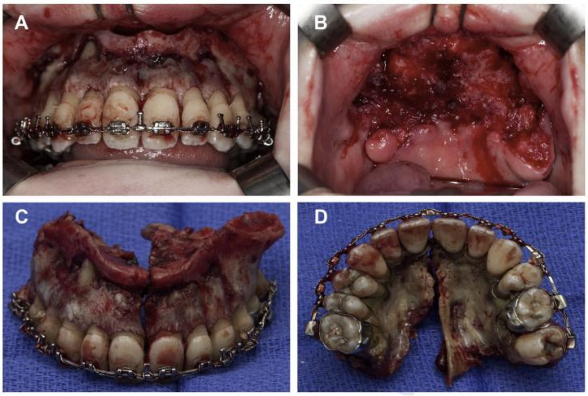

Figure 5. Necrosis occurring in the maxilla following LeFort I osteotomy. A, Surgical exposure of the necrotic maxilla. B, Total maxillary defect resulting from the removal of the necrotic maxillary specimen. C, Appearance of the debrided maxillary specimen. D, Appearance showing midline palatal suture necrosis of the maxillary specimen. (Ettinger et al., 2020)

4.6.CONDYLAR RESORBTION AND TME PROBLEMS

Temporomandibular joint disorders (TMJ) are common complications of orthognathic surgery. In the postoperative period, patients may experience various issues, including TMJ dysfunction resulting from condylar sagging, morphological changes of the condylar surface, condylar resorption, and malocclusion. Following orthognathic surgery, symptoms such as TMJ pain, joint noises, myofascial pain, and functional limitations may be observed. However, orthognathic surgery is known not only to cause TMJ-related complications but also to contribute to the correction of pre-existing TMJ pathologies. Temporomandibular joint (TMJ) disorders encompass all clinical conditions involving the masticatory muscles, the TMJ itself, the surrounding osseous and soft tissues, or combinations thereof. Consequently, surgeons must thoroughly evaluate patients' pre-existing TMJ symptoms prior to surgery and tailor treatment plans accordingly to minimize the risk of symptom exacerbation.

Condylar resorption, which may occur following orthognathic surgery, develops as a result of changes in condylar position within the glenoid fossa and mechanical loading. If these changes remain within the adaptive capacity of the temporomandibular joint (TMJ), no clinical or radiological manifestations are expected.

Condylar resorption is a progressive condition diagnosed through a combined assessment of clinical and radiological findings. Initial signs typically appear six months or more after mandibular advancement and may progress for up to two years postoperatively. Regardless of the presence of TMJ symptoms, patients may report gradual deterioration in occlusion and facial aesthetics over time. Significant risk factors for condylar resorption include radiographic signs of osteoarthritis, pre-existing temporomandibular joint disorders, mandibular hypoplasia, posteriorly inclined condylar neck, counterclockwise mandibular rotation, bimaxillary surgery, large mandibular advancements, prolonged intermaxillary fixation, female sex, high mandibular plane angle, small condylar size, advanced age, and Class II deformities requiring extensive mandibular advancement. Unlike other orthognathic surgical complications, condylar resorption may occur even years postoperatively. Therefore, at-risk patients should be monitored regularly over the long term.

Condylar resorption results in a reduction in posterior facial and ramus height, mandibular retrognathia and anterior open bite. Bilateral condylar resorption results in an anterior open bite, a Class II malocclusion and retrognathia, whereas unilateral cases present with laterognathia, a contralateral open bite and a Class II malocclusion. Diagnosis involves the use of radiological methods such as panoramic radiography, lateral cephalometric radiography, computed tomography (CT) and magnetic resonance imaging (MRI).

Prevention of condylar resorption primarily requires the control or elimination of risk factors, as well as the management of occlusal instability. Therapeutic approaches include conservative methods, such as splint therapy, physical rehabilitation, and anti-inflammatory medication, as well as surgical interventions, including orthognathic surgery, distraction osteogenesis, condylectomy, and reconstruction. Identifying risk factors prior to surgery is essential to limit mandibular advancement, compensate with additional maxillary osteotomy, and apply rigid fixation with non-traumatic, neutral condyle repositioning. Long-term postoperative follow-up is aalso important for preventing complications. (Catherine, Breton, & Bouletreau, 2016; Friscia et al., 2017; Jędrzejewski, Smektała, Sporniak-Tutak, & Olszewski, 2015; Jung, Kim, Park, & Jung, 2015)

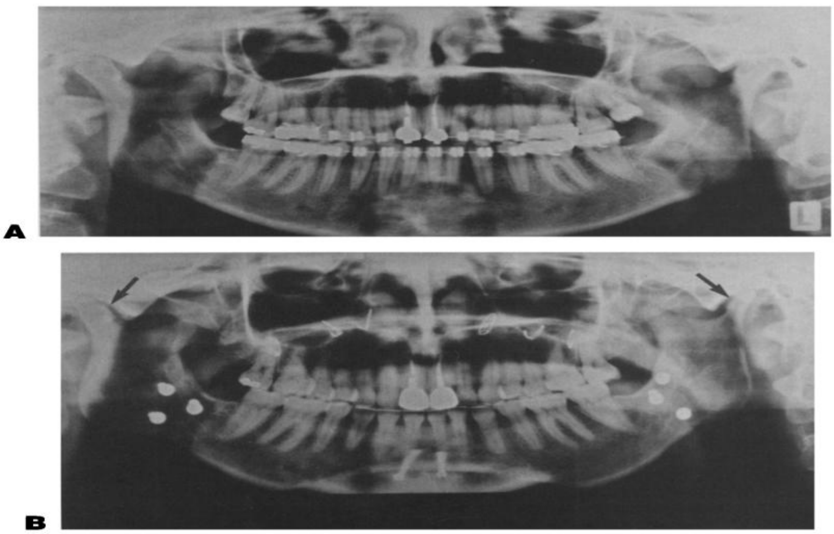

Figure 6. A, Preoperative condition. B, Condyle resorption observed on the anterior-superior surface 2 years after surgery, more pronounced on the left side. (Hwang et al., 2000)

4.7. NEUROPATHIC PAIN

When sagittal split osteotomy is performed, direct damage to the inferior alveolar nerve and exposed bone tissue can result in partial axonal injury. Such damage is considered one of the fundamental mechanisms in the development of neuropathic pain. Furthermore, perineural inflammation can increase spontaneous nerve activity without causing direct nerve trunk damage. Clinical observations suggest that neuropathic pain may persist for up to one year following surgery. Therefore, early diagnosis and effective management are of great importance. Neuropathic pain is most frequently reported in the literature after sagittal split osteotomy and is rarely seen after maxillary orthognathic surgery. (Y.-K. Kim, 2017; Politis, Lambrichts, & Agbaje, 2014)

4.8. NASOLACRIMAL DUCT OBSTRUCTION AND EPIPHORA

Nasolacrimal duct obstruction and the resulting epiphora are among the complications rarely reported in the literature, and can lead to postoperative discomfort and permanent nasolacrimal dysfunction. This condition primarily occurs following LeFort I osteotomy. During maxillofacial surgery, there is a risk of injury to the distal opening of the nasolacrimal duct and the anterior wall of the lacrimal sac. The nasolacrimal duct opens into the inferior meatus via the Hasner valve. Changes to the size or position of this anatomical opening, or functional obstructions, can increase the risk of injury to the nasolacrimal duct during surgery, which can subsequently cause epiphora.

Epiphora is a clinical manifestation resulting from impaired tear drainage in the lacrimal system. It may reduce visual acuity and render contact lens use impossible. A minimum distance of 5 mm should be maintained between the osteotomy levels and the nasolacrimal duct. Epiphora following orthognathic surgery is typically caused by injuries related to edema or inflammation of the nasal mucosa. It may be overlooked during the postoperative period due to pain, significant edema, or bleeding. Furthermore, patients often do not report this condition unless specifically asked. Therefore, surgeons should be aware of this possibility and actively inquire about it during postoperative evaluations.

Magnetic resonance imaging (MRI), computed tomography (CT), dacryocystography, and spiral CT with topical contrast media can be used alongside clinical examination to evaluate the nasolacrimal system and determine the level of obstruction. Epiphora is usually transient. Management typically involves local massage, nasal decongestants, and topical antibiotic or steroid solutions. If conservative measures are ineffective, dacryocystorhinostomy may be recommended. (Jang, Kim, Choi, & Jang, 2013; Ozcan, Dergin, & Basa, 2018)

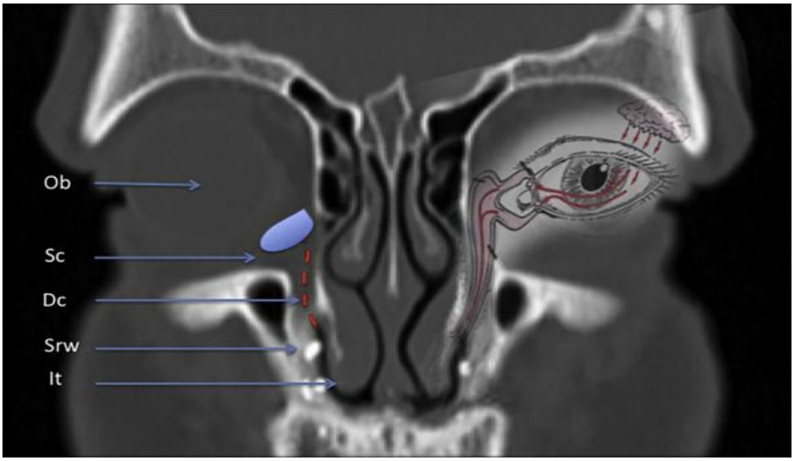

Figure 7. Le Fort I osteotomy related to the nasolacrimal system. Ob: Orbit; Sc: Lacrimal Sac; Dc: Nasolacrimal Duct; Srw: Fixation Screw; It: Inferior Nasal Bone. (Ozcan et al., 2018)

4.9.CHANGES IN NASAL MORPHOLOGY

Changes to the maxillomandibular skeleton directly affect the overlying facial soft tissues. As a central facial structure, the nose plays a key role in both facial expression and aesthetics. Therefore, nasal morphology must always be carefully considered when performing surgical procedures aimed at correcting or altering facial aesthetics. Due to its prominent midline position on the face, even minor nasal asymmetries and irregularities are readily detectable by both patients and surgeons. Patients should therefore be informed that rhinoplasty may be required if aesthetic or functional complications arise following orthognathic surgery.

Due to the close anatomical relationship between the maxilla and the nose, Le Fort I osteotomies have a more pronounced impact on nasal appearance compared to other orthognathic procedures. Widening of the alar base is observed in nearly all Le Fort I osteotomies, regardless of whether the maxilla is advanced or set back. In such cases, simultaneous rhinoplasty procedures may be performed to achieve the desired aesthetic outcome. Additionally, several researchers have described modifications to standard Le Fort I osteotomies and alternative surgical approaches aimed at controlling postoperative changes in nasal morphology.

Advancement and superior repositioning of the maxilla may elevate the nasal tip and widen the alar base. Nasal septal deviation most commonly occurs following Le Fort I osteotomies, particularly when the maxilla is repositioned superiorly. Regardless of the amount of maxillary advancement and the presence of anterior or posterior impaction, in most cases, there is a change in the shape of the tip of the nose, an increase in the width of the nose, and upward rotation of the nose. In addition, it has been reported that some patients may develop postoperative nasal obstruction. (Altman & Oeltjen, 2007; Dantas, Silveira, Vasconcelos, & Porto, 2015)

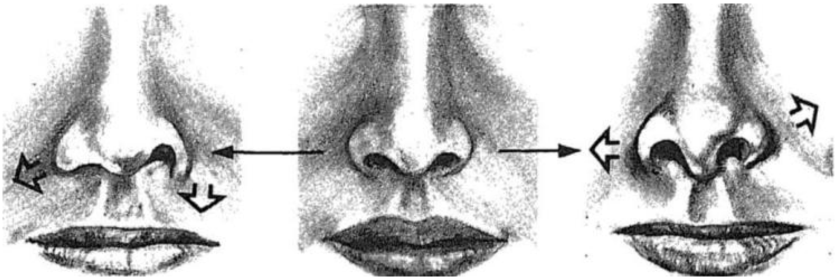

Figure 8. Nasal widening may occur in maxillary surgery if soft tissues are not reconstructed simultaneously. (Schendel & Carlotti Jr, 1991)

Figure 9. Changes that may occur in the nasal profile with maxillary surgery. (Schendel & Carlotti Jr, 1991)

4.10.SINUS PROBLEMS

Patients scheduled for orthognathic surgery should undergo a comprehensive sinus evaluation prior to the procedure. If sinus pathology is detected preoperatively, sinus dysfunction has been reported to worsen following maxillary surgery. Conversely, chronic hypoventilation is common in cases of maxillary hypoplasia, and it is thought that maxillary surgery in such cases may exert a positive effect on sinus infections by correcting nasal sinus hypoventilation.

Anatomical variations (e.g. concha bullosa, septal deviation and paradoxical turbinate concha) can increase the risk of infection by obstructing the drainage of the maxillary sinuses. Furthermore, maxillary osteotomy and prolonged intubation can obstruct sinus drainage, resulting in mucus stasis and making patients susceptible to bacterial or fungal sinus infections.

Sinus-related complications are rarely observed following Le Fort surgery. The reported incidence of postoperative maxillary sinusitis after Le Fort I osteotomy ranges from 0.6% to 4.76%. In general, the majority of the soft and hard tissues associated with the maxillary sinus return to their normal anatomical and functional state within six months postoperatively. (Ferri, Druelle, Schlund, Bricout, & Nicot, 2019; Jędrzejewski et al., 2015)

4.11.COMPLICATIONS RELATED TO FIXATION MATERIALS

Maxillomandibular fixation materials are extremely small and require the surgeon to pay close attention during the fixation procedure. Otherwise, there is a risk of the material becoming lost within the surgical field. Depending on the surgical fixation materials used, complications such as surgical wound dehiscence, screw loss, fixation loss, plate retention, plate fracture, mobility in bone segments, bone necrosis, surgical dehiscence and infection associated with the fixation material or secondary to fixation loss may develop. In such cases, removal of the plates and screws may become necessary. Manipulation of these structures can result in fracture of the fixation materials, leading to the presence of foreign bodies in the postoperative period. The most common foreign bodies encountered during revision surgeries are orthodontic brackets, screw heads, and fractured surgical drills. While fixation materials generally do not cause problems for patients in the short term, some may be able to palpate the plate beneath the mucosa in the long term. Once bone healing is complete, the plates can be removed at a later stage. (Friscia et al., 2017; Sousa & Turrini, 2012)

4.12.NAUSEA AND VOMITING

Postoperative nausea and vomiting (PONV) remains one of the most common and distressing complications experienced by both inpatients and outpatients following surgery. Although generally not life-threatening, PONV can lead to serious adverse outcomes, including dehydration, oesophageal rupture, surgical wound dehiscence, electrolyte imbalances, bleeding, haematoma formation, and aspiration of gastric contents. These complications may increase healthcare costs by prolonging hospital stays or necessitating readmission.

Lip numbness, orofacial oedema, and blood swallowing are frequently observed in the early postoperative period following orthognathic procedures involving the maxilla. The combination of these factors may contribute to an increased prevalence of PONV. Age and gender are well-established risk factors for PONV. In addition, intraoral bleeding and the continuous swallowing of blood have been reported to trigger nausea and vomiting. Evidence from the literature also suggests that postoperative pain may play a role in the development of PONV. Although the risk of PONV has been reported to be higher in patients undergoing bimaxillary surgery, no significant difference has been observed between patients undergoing isolated maxillary or mandibular surgery. (Phillips, Brookes, Rich, Arbon, & Turvey, 2015; Silva, O'Ryan, & Poor, 2006)

4.13.PSEUDOANEURYSM

A pseudoaneurysm, sometimes mischaracterized as an arteriovenous fistula, is defined as an abnormal and localized dilation of the arterial wall. In contrast to true aneurysms, pseudoaneurysms do not involve all layers of the vessel wall. These lesions develop when blood escapes from the vessel lumen and accumulates within a fibrous capsule surrounding the adjacent tissue. Although rare, pseudoaneurysms represent potentially serious complications of orthognathic surgery. Clinically, they may manifest as facial swelling, delayed bleeding, or a soft, pulsatile mass.

The maxillary, facial, and inferior alveolar arteries are particularly susceptible to pseudoaneurysm formation due to their anatomical course. In cases of minor vascular injury, spontaneous thrombosis may occur through platelet aggregation, allowing the haematoma to undergo physiological resolution. However, when haemostasis is insufficient, persistent bleeding ensues, making pseudoaneurysm formation inevitable. Patients frequently report a pulsating sensation in regions recently subjected to trauma or surgical intervention. Differential diagnoses include tumours, haematomas, abscesses, and lipomas; however, these entities typically lack pulsations or audible murmurs. Advanced imaging modalities such as computed tomography, magnetic resonance imaging, and ultrasonography are valuable tools for confirming the diagnosis. (de Lima Neto, de Albuquerque Maranhão, & de Oliveira Neto, 2019; Y.-K. Kim, 2017)

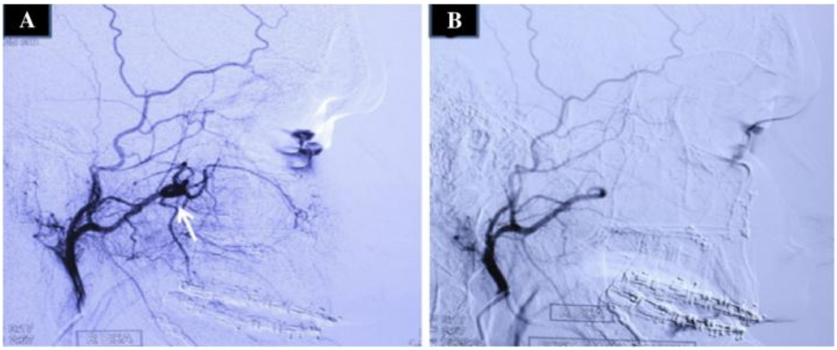

Figure 10. A, Digital Angiography (Lateral view) shows a pseudoaneurysm of the right sphenopalatine artery. B, After embolization. (Kumar, Kaur, Singh, Rattan, & Rai, 2021)

4.14.PSYCHOLOGICAL CHANGES

Individuals with dental and facial deformities frequently experience feelings of inferiority related to their appearance. In addition, they often encounter functional impairments, such as difficulties in mastication. Consequently, to ensure patient satisfaction and psychological well-being, it is essential to address psychological changes alongside functional and aesthetic improvements throughout the orthognathic surgery treatment process.

The main reasons for dissatisfaction with the surgery included temporary sensory disturbances and inadequate facial healing. Difficulties in speaking and eating due to intermaxillary fixation in the postoperative period were described by patients as the most painful experience, followed by breathing difficulties, swelling, and pain.

Providing patients with preoperative information about potential postoperative discomfort can help reduce anxiety and concerns, thereby contributing to increased satisfaction with surgical outcomes. A general improvement in quality of life, particularly in psychological and social domains, is typically observed following orthognathic surgery. However, because depression can negatively impact quality of life, patients should be systematically screened for depressive symptoms prior to surgery and referred for appropriate treatment when necessary.

Patients' expectations of surgical outcomes may differ from clinicians' predictions and, in some cases, may be unrealistic. Therefore, it is essential to regularly assess and manage patients' expectations throughout the treatment process. (Y.-K. Kim, 2017; Liddle, Baker, Smith, & Thompson, 2015; Moon & Kim, 2016)

4.15.RESPIRATORY SYSTEM COMPLICATIONS

Postoperative respiratory failure can result from nasal mucosal oedema or injury, narrowing of the nasal airway, intermaxillary fixation (IMF), blood aspiration, oedema, bleeding or haematoma in the floor of the mouth, a retained throat pack, dislodged orthodontic brackets entering the airway, or prolonged surgery. Dyspnoea caused by bleeding or accumulated secretions can be prevented by avoiding excessive ventilation during general anaesthesia and minimizing intraoperative trauma. Posterior displacement of the mandible during sagittal split osteotomy may narrow the airway; therefore, the risk of postoperative respiratory failure can be reduced by carefully determining the required amount of mandibular retraction during surgical planning. Snoring or obstructive sleep apnoea (OSA) may develop after orthognathic surgery due to changes in hyoid bone position and subsequent airway narrowing. Blood accumulation in the nasopharynx is common after maxillary surgery and may result from nasal mucosal injury, drainage from the maxillary sinus, or elevated postoperative blood pressure, potentially leading to re-bleeding. The widespread use of rigid internal fixation with screws and plates has significantly reduced the need for postoperative IMF. When respiratory distress occurs after orthognathic surgery, releasing the IMF is often sufficient; however, this intervention may be inadequate in cases of respiratory failure caused by surgical, anaesthetic, or metabolic factors. (Y.-K. Kim, 2017; Politis, Kunz, Schepers, Vrielinck, & Lambrichts, 2012)

4.16.AURICULOTEMPORAL SYNDROME (FREY SYNDROME)

Frey syndrome (auriculotemporal syndrome) is a clinical condition characterized by episodes of increased temperature, flushing, and sweating in the preauricular region of the face, typically triggered by gustatory stimulation. In the pathophysiology of the syndrome, aberrant regeneration of severed parasympathetic nerve fibers following parotid gland injury plays a critical role. This abnormal reinnervation process is thought to result in parasympathetic fibers, which normally innervate the salivary glands, forming connections with sweat glands and subcutaneous vascular structures, thereby inducing localized vasodilation and sweating during mastication.

Frey syndrome most commonly arises as a complication of parotid gland or temporomandibular joint surgery, although it has been rarely reported following orthognathic procedures. The condition may develop when the auriculotemporal nerve is injured during interventions such as sagittal split ramus osteotomy or vertical ramus osteotomy. The minor starch-iodine test is a highly sensitive diagnostic method; in this test, iodine and starch are applied to the affected area, and the resulting color change is evaluated to determine the extent and distribution of sweating. Additionally, thermography can serve as a supplementary diagnostic tool to demonstrate the increased local heat production characteristic of Frey syndrome.

Although Frey syndrome may resolve spontaneously in some cases, it is primarily managed through medical or surgical interventions. Currently, the most effective and reliable treatment is subcutaneous injection of botulinum toxin into the affected area, with multiple studies reporting significant and long-lasting symptom reduction. Alternative therapeutic options include topical administration of anticholinergic agents such as scopolamine and glycopyrrolate. Additionally, the use of topical antiperspirants containing 20% aluminum chloride, and, in rare cases, topical application of clonidine, an alpha-adrenergic agonist, have also been documented in the literature. (Kragstrup, Christensen, Fejerskov, & Wenzel, 2011; Sohn & Kim, 2016)

5.CONCLUSION

Orthognathic surgery is recognized as a treatment method with high clinical efficacy in terms of both improving facial aesthetics and improving maxillofacial functions. However, as with any surgical procedure, orthognathic surgery carries certain risks of complications.

Preoperative planning is critical in reducing the risk of complications. In particular, three-dimensional imaging techniques and virtual surgical planning increase the precision of osteotomies and improve surgical predictability. The surgeon's experience, the accuracy of the techniques used, and intraoperative decision-making processes have a direct impact on both postoperative recovery and the safety of long-term outcomes.

Regular patient follow-up and comprehensive education in the postoperative period enable the early detection of complications and the implementation of appropriate management strategies. Furthermore, effective surgeon-patient communication and the information process ensure that the patient's expectations are managed realistically and that the surgical process is carried out in an informed manner.

In conclusion, the success of orthognathic surgery depends not only on technical proficiency and surgical planning, but also on a multidisciplinary approach, appropriate case selection, systematic postoperative follow-up, and effective communication processes. Although complications cannot be completely eliminated, these measures enable risks to be minimized and patient safety to be maximized. In the future, advancing imaging technologies and individualized surgical planning have the potential to further reduce complication rates and increase the predictability of surgical outcomes.

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