DENTOMAXILLOFACIAL DIAGNOSTIC IMAGING SCIENCES AND ORAL AND MAXILLOFACIAL SURGERY

Editör:
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BİDGE Yayınları

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CHAPTER 1
Medication-Related Osteonecrosis of the Jaw: Prevention, Diagnosis, and Contemporary Management

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Introduction

Medication-related osteonecrosis of the jaw has become one of the most important drug-associated complications encountered in contemporary oral and maxillofacial practice. The condition was initially recognized in the early 2000s after clinicians reported persistent areas of exposed and necrotic jawbone in patients receiving intravenous bisphosphonates for multiple myeloma and metastatic malignancy (Marx, 2003 & Ruggiero et al., 2004). These early observations established a relationship between potent inhibition of bone resorption and a distinctive form of osteonecrosis affecting the maxilla and mandible. The disorder was initially termed bisphosphonate-related osteonecrosis of the jaw, but subsequent reports of similar lesions in patients treated with denosumab, antiangiogenic agents, and other targeted therapies led to adoption of the broader term medication-related osteonecrosis of the jaw(Ruggiero et al., 2014 & Ruggiero et al, 2022).

The emergence of MRONJ created an important clinical dilemma because the medications implicated in its development provide substantial systemic benefits. Antiresorptive therapy reduces the risk of skeletal-related events in patients with metastatic bone disease and multiple myeloma and plays a major role in preventing fragility fractures in patients with osteoporosis (Khan et al., 2015 & Ruggiero et al, 2022 & Curtis et al., 2024). The presence of a potential risk of jaw osteonecrosis should therefore not result in indiscriminate discontinuation or avoidance of these therapies. Instead, MRONJ management requires careful comparison of the relatively uncommon oral complication against the often substantial skeletal and oncological benefits of treatment (Yarom et al., 2019 & Ruggiero et al, 2022).

The absolute risk of MRONJ differs considerably according to the underlying medical indication and treatment intensity. Patients receiving low-dose oral or parenteral antiresorptive therapy for osteoporosis generally have a substantially lower risk than patients receiving high-dose intravenous bisphosphonates or oncological doses of denosumab (Limones et al., 2020 & Ruggiero et al, 2022 & Pakdeemeechai et al., 2025). This distinction is particularly important when counseling patients, because excessive concern regarding MRONJ may result in inappropriate refusal of osteoporosis therapy and expose patients to preventable fractures. Conversely, individuals receiving intensive bone-modifying therapy for malignant disease warrant more extensive preventive dental assessment and closer surveillance.

The clinical spectrum of MRONJ is broad. The classical presentation consists of persistent exposed necrotic bone, but patients may also present with pain, swelling, purulent discharge, fistulation, unexplained tooth mobility, non-healing extraction sockets, neurosensory abnormalities, or radiographic changes before

obvious bone exposure develops (Ruggiero et al, 2022 & Bedogni et al., 2024). Advanced disease may extend beyond the alveolar process, compromise mandibular continuity, involve the maxillary sinus, produce oroantral or oronasal communication, or lead to pathological fracture. These manifestations may significantly impair mastication, speech, nutrition, and quality of life (Murphy & Mannion, 2020).

The understanding of MRONJ has evolved considerably over the past decade. Earlier treatment strategies frequently favored prolonged conservative care, with major surgery generally reserved for advanced or refractory lesions. More recent clinical evidence has demonstrated that appropriately planned surgery can result in predictable healing in selected patients with earlier-stage as well as advanced disease (Giudice, 2020 & Wei, 2025). This change is reflected in the AAOMS 2022 position paper, which acknowledges a broader role for operative treatment rather than restricting surgery to Stage 3 disease (Ruggiero et al, 2022). Nevertheless, international recommendations are not completely uniform. The 2024 Italian position paper, for example, gives greater emphasis to clinical-radiological staging and specific approaches to drug interruption, illustrating that differences in interpretation remain among professional groups (Bedogni at al., 2024).

The preventive dimension of MRONJ has simultaneously become increasingly important. Dental optimization before initiation of high-risk therapy, control of periodontal and periapical infection, maintenance of oral hygiene, elimination of traumatic prosthetic factors, and appropriate planning of dentoalveolar procedures represent essential components of modern management (Ruggiero et al, 2022 & Kim et al., 2025). Prevention is particularly important because established MRONJ can require prolonged treatment and, in advanced disease, extensive resective surgery.

The increasing use of cone-beam computed tomography, conventional computed tomography, magnetic resonance imaging, and other imaging techniques has further altered diagnostic and therapeutic pathways. MRONJ remains primarily a clinical diagnosis, but three-dimensional imaging can reveal disease extension beyond the clinically visible lesion and can be critical for surgical planning (Ko et al., 2024 & Yarom et al., 2025). Accordingly, the current concept of MRONJ extends beyond the simple presence of exposed bone and encompasses a complex interaction between pharmacological exposure, local inflammation, bone remodeling, mucosal integrity, microbial colonization, systemic health, and individual susceptibility.

Definition and Diagnostic Criteria

A standardized definition of MRONJ is necessary for clinical diagnosis, staging, epidemiological research, and comparison of therapeutic outcomes. According to the AAOMS 2022 position paper, a diagnosis of MRONJ is made when a patient has current or previous exposure to antiresorptive therapy, alone or in combination with immune-modulating or antiangiogenic medications, together with exposed bone or bone that can be probed through an intraoral or extraoral fistula in the maxillofacial region for more than eight weeks, in the absence of previous radiation therapy to the jaws or obvious metastatic disease involving the jaws (Ruggiero et al., 2022).

The MASCC/ISOO/ASCO guideline uses a closely related clinical framework and emphasizes that diagnosis should be established by clinicians experienced in the condition (Yarom et al., 2019). This definition remains useful because it differentiates MRONJ from other causes of jaw necrosis, particularly osteoradionecrosis, while simultaneously acknowledging that several medication classes may be implicated.

The traditional eight-week requirement was introduced to distinguish true osteonecrosis from transient delayed healing after trauma or dentoalveolar surgery. Nevertheless, strict dependence on an eight-week period has increasingly been questioned when clinical and radiographic findings are strongly suggestive of necrotic bone. The 2025 Korean multidisciplinary position statement, for example, preserves the traditional diagnostic framework but allows an earlier diagnosis when convincing clinical or imaging evidence demonstrates necrotic bone before eight weeks have elapsed (Kim et al., 2025). This reflects a growing interest in earlier recognition rather than waiting for prolonged exposure or progression to establish diagnostic certainty.

Another important diagnostic challenge is the existence of patients without clinically exposed bone. AAOMS retains Stage 0 to describe individuals with relevant medication exposure who present with nonspecific symptoms or radiographic abnormalities suggestive of MRONJ despite the absence of exposed necrotic bone (Ruggiero et al., 2022). These patients may complain of unexplained odontalgia, dull bone pain, altered sensation, or sinus-related discomfort, while clinical examination may demonstrate swelling or unexplained tooth mobility. Imaging may reveal areas of sclerosis, persistent extraction sockets, altered trabecular architecture, or abnormalities of the lamina dura.

Stage 0 remains controversial because its manifestations overlap with much more common dental and maxillofacial conditions. Periapical infection, periodontal disease, temporomandibular disorders, odontogenic sinusitis, neuropathic pain, chronic osteomyelitis, fibro-osseous lesions, primary malignancy, and metastatic disease may all produce similar symptoms or radiographic changes (Ruggiero et al., 2022 & Yarom et al., 2025). For this reason, the diagnosis should not be made solely because a patient has a history of antiresorptive medication use.

Histopathological confirmation is not required in routine MRONJ diagnosis. Biopsy should generally be reserved for circumstances in which malignancy, metastasis, or another pathological process cannot be excluded (Yarom et al., 2025). This consideration is particularly relevant in oncology patients, because a destructive jaw lesion may represent metastatic disease rather than MRONJ. Since biopsy itself creates additional bone injury, the potential diagnostic benefit should be weighed against the possibility of aggravating local tissue damage.

Medications Associated with MRONJ

Bisphosphonates

Bisphosphonates are among the most extensively studied medications associated with MRONJ. These compounds are structural analogues of inorganic pyrophosphate and have a strong affinity for hydroxyapatite. Following administration, they

accumulate preferentially in areas of active bone remodeling and remain incorporated within mineralized tissue for prolonged periods (Cremers et al., 2019 & Jiang et al., 2024).

Nitrogen-containing bisphosphonates such as zoledronic acid, alendronate, risedronate, and ibandronate inhibit farnesyl pyrophosphate synthase within the mevalonate pathway. This interferes with intracellular protein prenylation, impairs osteoclast function, and promotes osteoclast apoptosis, ultimately producing substantial inhibition of bone resorption (Cremers et al., 2019 & Jiang et al., 2024). Their pharmacological effects are beneficial in diseases characterized by excessive skeletal resorption but may also reduce the ability of jawbone to respond to inflammation, microdamage, and surgical trauma.

The risk associated with bisphosphonates is not uniform. Patients receiving high-dose intravenous zoledronic acid for skeletal complications of malignant disease have a substantially higher risk of MRONJ than patients receiving conventional oral bisphosphonates for osteoporosis (Limones et al., 2020 & Ruggiero et al., 2022). Cumulative dose and duration of exposure also contribute to risk, although no single duration threshold accurately predicts disease.

A particularly important pharmacological characteristic of bisphosphonates is their prolonged skeletal retention. Because they can remain incorporated in bone for years, short-term cessation may not meaningfully reduce local exposure. This pharmacokinetic feature is one of the reasons why the clinical value of temporary bisphosphonate discontinuation before dental surgery remains uncertain (Ruggiero et al., 2022 & Aboalela et al., 2022).

Denosumab

Denosumab is a fully human monoclonal antibody directed against receptor activator of nuclear factor-kappa B ligand, commonly referred to as RANKL. By preventing the interaction between RANKL and RANK on osteoclast precursors and mature osteoclasts, denosumab inhibits osteoclast formation, function, and survival (Jiang et al., 2024).

Its pharmacological behavior differs substantially from that of bisphosphonates. Denosumab does not bind to hydroxyapatite and does not accumulate within bone. The antiresorptive effect therefore decreases after cessation. However, this reversibility does not necessarily make discontinuation clinically advantageous. In patients receiving denosumab for osteoporosis, delayed administration or discontinuation may lead to rapid rebound bone resorption and an increased risk of multiple vertebral fractures (Ruggiero et al., 2022 & Curtis et al., 2024).

This distinction is particularly important when planning dentoalveolar surgery. A dentist or oral surgeon should not independently advise a patient to discontinue denosumab without coordination with the prescribing clinician. Any alteration in timing should consider the patient's fracture risk, the indication for therapy, the urgency of dental treatment, and the potential consequences of delaying the next dose (Ruggiero et al., 2022 & Kim et al., 2025).

In oncology populations, high-dose denosumab has been associated with a clinically relevant MRONJ risk. Systematic reviews comparing denosumab with zoledronic acid suggest that the incidence is at least comparable and may be somewhat higher with denosumab in some treatment settings (Limones et al., 2020). Sequential exposure to zoledronic acid and denosumab may further increase risk because of cumulative suppression of bone resorption (Srivastava et al., 2021).

Antiangiogenic and Other Targeted Agents

MRONJ has also been reported in association with several antiangiogenic and targeted anticancer agents. These medications can interfere with vascular endothelial growth factor signaling, endothelial function, immune pathways, or intracellular signaling mechanisms involved in tissue repair (Otto et al., 2018 & Ruggiero et al., 2022).

The independent contribution of individual agents is difficult to determine because patients with advanced malignancy frequently receive multidrug treatment. Antiangiogenic therapy may be given together with antiresorptive medication, corticosteroids, chemotherapy, or immunotherapy, making it difficult to isolate the effect of a single drug. For this reason, contemporary risk assessment should include the entire medication history rather than focusing exclusively on bisphosphonates and denosumab.

Epidemiology

The reported incidence of MRONJ varies considerably according to the medication, therapeutic indication, dosage, cumulative exposure, study population, diagnostic criteria, and duration of observation (Ruggiero et al., 2022 & Bedogni et al., 2024). The most clinically meaningful distinction is between patients treated for osteoporosis and those receiving high-dose therapy for malignant disease.

In osteoporosis populations, the absolute incidence remains low. Although long-term exposure may increase risk, the frequency of MRONJ is substantially lower than the frequency of major osteoporotic fractures in untreated high-risk patients (Ruggiero et al., 2022). Consequently, discussion of MRONJ in osteoporosis should be placed within an appropriate risk-benefit context. Fear of a rare oral complication should not routinely outweigh the proven benefits of fracture prevention.

The situation is different in oncology. Patients with multiple myeloma or metastatic solid tumors may receive potent antiresorptive therapy at considerably higher doses and shorter intervals. Their cumulative exposure is greater, and they often have additional systemic factors including malignant disease, chemotherapy, corticosteroid therapy, anemia, immunosuppression, and impaired nutritional status (Limones et al., 2020 & Ruggiero et al., 2022). As a result, the incidence of MRONJ in these populations is considerably higher.

Duration of treatment is relevant, but it should not be interpreted as an isolated variable. The probability of disease reflects the cumulative interaction between pharmacological exposure and local oral conditions. A patient with high-dose antiresorptive exposure, advanced periodontal disease, poorly controlled diabetes, and the need for repeated dentoalveolar surgery has a markedly different risk profile from an otherwise healthy osteoporosis patient receiving short-term oral bisphosphonate therapy.

Real-world estimates may also differ from randomized clinical trials because MRONJ may be underdiagnosed when standardized oral examinations are not incorporated into follow-up. Conversely, referral-center cohorts may contain disproportionate

numbers of advanced cases and therefore overrepresent severe disease.

Pathophysiology

The pathophysiology of MRONJ remains incompletely understood, and no single mechanism can account for the entire clinical spectrum. Current evidence supports a multifactorial model in which profound suppression of bone remodeling interacts with infection, inflammation, immune dysfunction, impaired angiogenesis, mucosal injury, and the particular biological characteristics of the jaws (Lončar Brzak et al., 2023 & Jiang et al., 2024).

Bone remodeling is central to skeletal homeostasis. Osteoclast-mediated resorption removes damaged or aged bone, while osteoblasts subsequently replace it with new tissue. Bisphosphonates and denosumab interfere with this process by suppressing osteoclast function through different molecular mechanisms (Jiang et al., 2024). Although this effect is therapeutically desirable in osteoporosis and malignant skeletal disease, excessive suppression may compromise the capacity of bone to respond to microdamage and infection.

The jawbones are exposed to conditions that distinguish them from most other skeletal sites. They experience constant mechanical loading associated with mastication, rapid remodeling of alveolar bone, frequent inflammatory challenges arising from the dentition,

and direct proximity to a dense polymicrobial environment. Periodontal and periapical tissues can provide a pathway through which microorganisms and inflammatory mediators gain access to alveolar bone.

Local inflammation has therefore become a central component of contemporary pathogenic models. Periodontitis, apical periodontitis, peri-implantitis, and other odontogenic infections may produce inflammatory changes before any surgical procedure is performed (Aghaloo et al., 2011 & Mota et al., 2025). Tooth extraction is frequently described as a precipitating event, but this association must be interpreted carefully because teeth are generally extracted as a consequence of pre-existing disease. Extraction may therefore represent the final event in a biological sequence that has already involved infection, inflammatory bone damage, and impaired remodeling.

Once bone becomes exposed to the oral cavity, microbial colonization may further perpetuate inflammation. Biofilms containing mixed bacterial populations and Actinomyces species are frequently identified on necrotic surfaces. Although it remains uncertain whether specific microorganisms initiate MRONJ, persistent bacterial colonization can contribute to chronic inflammation and delayed healing.

Angiogenesis has also been implicated in disease development. Effective healing of bone and oral mucosa requires adequate vascularization, and antiangiogenic medications can disrupt endothelial signaling. Nevertheless, MRONJ should not be regarded simply as an ischemic phenomenon. Vascular alterations appear to interact with suppression of remodeling and local inflammation rather than acting as the sole pathogenic mechanism (Otto et al., 2018 & Jiang et al., 2024).

Immune dysfunction may further influence susceptibility. Patients receiving high-dose antiresorptive therapy for cancer frequently undergo chemotherapy, corticosteroid treatment, immunotherapy, or other systemic therapies that may alter neutrophil, macrophage, lymphocyte, and cytokine function. Impaired immune responses may reduce resistance to oral microbial challenges and compromise resolution of inflammation (Otto et al., 2018 & Kawahara et al., 2021).

Soft-tissue healing also appears relevant. The oral mucosa normally creates a protective barrier between the underlying jawbone and the microbial environment. Experimental studies have suggested that bisphosphonates may impair proliferation or migration of epithelial cells and fibroblasts. Persistent mucosal defects following extraction or trauma could therefore facilitate prolonged exposure of poorly remodeling bone to oral microorganisms.

These mechanisms are not mutually exclusive. The current view is that MRONJ results from interaction among suppressed remodeling, inflammation, infection, altered immunity, vascular changes, and impaired mucosal healing within a uniquely vulnerable anatomical environment (Lončar Brzak et al., 2023 & Jiang et al., 2024).

Risk Factors

The risk of MRONJ is determined by a combination of medication-related, systemic, and local oral factors. Treatment indication is among the strongest determinants, because oncology patients receiving high-dose antiresorptive therapy consistently demonstrate a greater risk than osteoporosis patients treated with conventional regimens (Limones et al., 2020 & Ruggiero et al., 2022). Potency, cumulative exposure, treatment duration, and sequential administration of different antiresorptive agents may further modify this risk (Srivastava et al., 2021 & Ruggiero et al., 2022).

Concomitant medications may contribute additional biological stress. Corticosteroids, cytotoxic chemotherapy, antiangiogenic agents, and selected immune-modulating therapies can impair immunity, vascular function, and wound healing. The degree to which each medication independently increases risk is difficult to quantify because oncology patients commonly receive several drugs simultaneously.

Local oral disease is equally important. Tooth extraction remains the most frequently reported preceding event, but the underlying reason for extraction must be considered (Aghaloo et al., 2011 & Mota et al., 2025). Advanced periodontal disease and apical infection may already have altered the local osseous environment before surgery. The combination of inflammatory disease, suppressed bone remodeling, microbial contamination, and surgical trauma may be more important than the mechanical act of extraction alone.

Poor oral hygiene can indirectly increase risk by permitting periodontal and carious disease to progress until surgical treatment

becomes necessary. Peri-implantitis creates a similar chronic inflammatory environment around implants and may contribute to late-onset implant-associated MRONJ. Repetitive mucosal trauma from poorly fitting prostheses may also expose vulnerable bone, particularly over thin mucosa covering bony prominences.

Systemic factors such as advanced age, diabetes mellitus, smoking, anemia, impaired nutritional status, corticosteroid exposure, and immunosuppression have been associated with disease in observational studies (Khan et al., 2015 & Ruggiero et al., 2022). These associations are heterogeneous, and no single systemic variable should be used as an absolute predictor. Instead, they should contribute to an integrated assessment of overall susceptibility.

Dental implants require particularly individualized consideration. Elective implant placement in patients receiving high-dose antiresorptive therapy for malignant disease is generally approached with substantial caution (Ruggiero et al., 2022). In patients receiving conventional osteoporosis therapy, implant placement is not universally contraindicated, but informed consent should include discussion of MRONJ, peri-implant disease, and the possibility that complications may emerge even after successful osseointegration. Recent systematic evidence has continued to examine implant failure and MRONJ in antiresorptive-treated osteoporosis populations, emphasizing that risk should be interpreted according to drug type and cumulative exposure rather than considering all implant patients equivalent (Andersen et al., 2025).

Clinical Presentation

The clinical manifestations of MRONJ range from small, asymptomatic areas of exposed bone to extensive destructive disease associated with pain, infection, fistulation, and fracture. Persistent exposed necrotic bone remains the most characteristic finding, but the appearance of the lesion can vary substantially according to duration, infection, and anatomical location (Ruggiero et al., 2022).

Patients with symptomatic disease may report dull or aching pain, localized swelling, purulent drainage, halitosis, mucosal ulceration, difficulty wearing removable prostheses, or a persistent non-healing extraction site. Unexplained mobility of adjacent teeth may occur when inflammatory and necrotic changes compromise supporting bone. In mandibular lesions, altered sensation involving the lower lip or chin may develop when disease approaches the inferior alveolar canal.

Advanced disease can cause substantial anatomical destruction. In the mandible, osteolysis may extend toward the inferior border and eventually compromise structural continuity, resulting in pathological fracture. In the maxilla, lesions may spread into the maxillary sinus and produce chronic sinus symptoms or oroantral communication. Extraoral fistulation may occur when infection and necrosis extend through surrounding soft tissues.

The absence of exposed bone does not completely exclude disease. Stage 0 patients may experience unexplained bone pain, altered sensation, persistent tooth-related symptoms without an obvious odontogenic source, or radiographic abnormalities. Because these findings overlap with common dental disorders, diagnosis must remain cautious and should rely on combined assessment of

medication history, clinical examination, imaging, and longitudinal evolution (Ruggiero et al., 2022 & Kim et al., 2025).

Imaging

Although MRONJ remains principally a clinical diagnosis, imaging plays an increasingly important role in defining disease extent, identifying complications, supporting differential diagnosis, monitoring progression, and planning surgery (Ko et al., 2024 & Yarom et al., 2025 & Ribeiro et al., 2025). The 2025 MASCC/ISOO clinical practice statement emphasizes that imaging should be selected according to the clinical question rather than performed routinely using a single standardized modality (Yarom et al., 2025).

Periapical radiography is useful for identifying conventional odontogenic causes of symptoms, including apical periodontitis, periodontal bone loss, retained roots, and dental fractures. Panoramic radiography provides a broader overview of both jaws and may demonstrate persistent extraction sockets, diffuse sclerosis, altered trabecular architecture, sequestration, cortical irregularity, osteolysis, or periosteal reaction.

Two-dimensional imaging has important limitations because the clinically significant extent of MRONJ may not be fully apparent. Cone-beam computed tomography provides three-dimensional visualization of mineralized tissues and is particularly valuable for demonstrating sequestra, cortical perforation, sclerosis, osteolysis, periosteal new bone formation, involvement of the

mandibular canal, and extension into the maxillary sinus (Ko et al., 2024). A 2024 review highlighted the ability of CBCT to characterize lesion extent more accurately than conventional radiography and to assist in surgical planning.

Conventional multidetector CT may be preferable when extensive disease, pathological fracture, deep soft-tissue infection, or broader craniofacial anatomy must be assessed. Contrast-enhanced CT can be particularly useful when abscess formation or extension into fascial spaces is suspected.

Magnetic resonance imaging provides information about bone marrow and soft tissue that cannot be obtained from conventional radiography. MRI may demonstrate marrow abnormalities beyond areas of obvious cortical destruction, although it is not required in every patient. Nuclear imaging techniques such as scintigraphy and PET/CT may show altered metabolic activity but lack specificity, because increased uptake can occur in infection, malignancy, and healing tissue as well as MRONJ (Yarom et al., 2025 & Ribeiro et al., 2025).

In oncology patients, imaging previously obtained for cancer surveillance should be reviewed before ordering additional studies. Existing CT, MRI, scintigraphic, or PET/CT examinations may already contain useful information regarding the jaws and may reduce unnecessary radiation exposure or duplicate investigations (Yarom et al., 2025).

Laboratory Assessment and Biomarkers

No laboratory biomarker has been sufficiently validated to diagnose MRONJ or reliably predict its development. Serum bone turnover markers, particularly C-terminal telopeptide, have historically attracted attention as possible predictors of surgical risk. However, available evidence has not supported a universally reliable threshold that can distinguish safe from unsafe dentoalveolar surgery (Ruggiero et al., 2022 & Yarom et al., 2025).

Accordingly, bone turnover markers should not replace comprehensive clinical assessment. A low or high value may reflect systemic skeletal turnover, but it does not directly measure the capacity of a specific area of jawbone to heal following surgery. Recent meta-analytic work has revisited the possible predictive value of serum C-terminal telopeptide, but the findings remain insufficient to justify routine use as a stand-alone decision tool.

Laboratory investigations should instead be tailored to systemic health and the planned procedure. In oncology patients, complete blood count may be important for identifying neutropenia, anemia, or thrombocytopenia. Renal function may influence antibiotic and analgesic selection, while coagulation status may be relevant when other medications increase bleeding risk. Glycemic control may also influence healing in patients with diabetes (Yarom et al., 2025).

Differential Diagnosis

The differential diagnosis of MRONJ includes a broad spectrum of dental and maxillofacial conditions. Chronic osteomyelitis, apical periodontitis, periodontal disease, alveolar osteitis, traumatic bone sequestration, fibro-osseous lesions, osteoradionecrosis, primary bone malignancy, metastatic disease, odontogenic sinusitis, and neuropathic pain may all produce overlapping clinical or radiographic findings (Ruggiero et al., 2022 & Yarom et al., 2025).

The medication history is important but should not dominate diagnostic reasoning. A patient receiving bisphosphonates can still develop conventional odontogenic infection, temporomandibular pain, metastatic disease, or another unrelated pathological process. Stage 0 presentations are particularly vulnerable to overdiagnosis because symptoms may be vague and radiographic findings nonspecific.

Biopsy should be considered when malignancy cannot reasonably be excluded. This is particularly important in patients with a previous cancer diagnosis and aggressive radiographic destruction. The indication should nevertheless be carefully considered because biopsy creates additional tissue trauma in an already compromised environment (Yarom et al., 2025).

Staging

AAOMS classifies patients as being at risk or as having Stage 0, Stage 1, Stage 2, or Stage 3 disease (Ruggiero et al., 2022). Patients who have been exposed to implicated medications but do not demonstrate necrotic bone are considered at risk. Their management is centered on prevention, education, maintenance of oral health, and surveillance rather than treatment of osteonecrosis.

Stage 0 is characterized by the absence of clinically exposed necrotic bone despite symptoms or radiographic findings that raise suspicion for MRONJ. These patients may experience unexplained pain, sensory abnormalities, tooth mobility, or swelling, while imaging may reveal sclerosis or abnormal trabeculation. Because the findings are not specific, longitudinal observation and exclusion of alternative diagnoses are essential.

Stage 1 is characterized by exposed necrotic bone or a fistula that probes to bone without clear clinical evidence of infection. Patients may be asymptomatic or minimally symptomatic. Local antimicrobial care, oral hygiene, and observation remain reasonable approaches, although limited surgery may also be considered when a well-defined sequestrum is present and can be removed with acceptable morbidity (Ruggiero et al., 2022).

Stage 2 includes exposed or probeable necrotic bone accompanied by clinical evidence of infection or inflammation and is commonly associated with pain, erythema, swelling, or purulent drainage. Antibiotics and analgesia may be required for infection control, but recurrent symptoms or persistent necrotic bone should prompt consideration of definitive surgical treatment.

Stage 3 represents advanced disease. Necrosis may extend beyond the alveolar process and result in pathological fracture, extraoral fistulation, oroantral or oronasal communication, or extensive osteolysis. Definitive surgery is often necessary when the patient's general condition allows it (Ruggiero et al., 2022).

Staging remains clinically useful for communication, but it should not function as the sole determinant of treatment. Symptom burden, radiographic disease extent, systemic health, oncological prognosis, medication indication, previous therapy, and patient preferences should all contribute to management decisions (Ruggiero et al., 2022 & Kim et al., 2025 & Yarom et al., 2025).

Prevention

Prevention remains one of the most effective approaches to reducing the morbidity associated with MRONJ. The ideal strategy begins before initiation of high-risk antiresorptive therapy, particularly in patients scheduled to receive intensive oncological regimens (Ruggiero et al., 2022 & Kim et al., 2025).

Comprehensive dental assessment should identify active caries, periodontal disease, apical pathology, teeth with a hopeless prognosis, peri-implant inflammation, poorly fitting prostheses, and other potential sources of infection or trauma. The goal is not indiscriminate extraction of questionable teeth but reduction of the likelihood that invasive treatment will be required once high-risk medication has commenced.

When nonrestorable or severely infected teeth are present, treatment should ideally be completed before initiation of high-dose therapy if the patient's medical condition permits adequate healing time. However, essential anticancer therapy should not be

unnecessarily delayed solely to complete elective dental procedures (Yarom et al., 2019).

Periodontal treatment and endodontic therapy play an important preventive role because preservation of strategically useful and predictably treatable teeth can reduce the need for extraction. Effective control of plaque-associated disease and regular maintenance also lower the probability that periodontal inflammation will progress during systemic treatment.

Patient education should accompany clinical intervention. Patients should understand that MRONJ is a serious but relatively uncommon complication and that risk differs substantially between osteoporosis and oncological regimens. They should be encouraged to report non-healing extraction sites, exposed bone, unexplained pain, swelling, drainage, or sensory disturbance. This education should be balanced to avoid creating unnecessary fear of medically indicated antiresorptive treatment.

The evidence supporting specific preventive procedures around extraction remains heterogeneous. A recent network meta-analysis found no single preventive intervention that was clearly superior for reducing MRONJ after tooth extraction, reinforcing the importance of overall risk reduction rather than reliance on one technique (Barone et al., 2025).

Tooth Extraction During Antiresorptive Therapy

Tooth extraction remains one of the most challenging decisions in patients exposed to antiresorptive medication. Avoidance of extraction at all costs is not an appropriate strategy because a severely infected or nonrestorable tooth may maintain

chronic inflammation within alveolar bone and potentially contribute to MRONJ development.

When extraction is necessary, the objective should be controlled removal of the dental source of infection while minimizing unnecessary trauma. Atraumatic technique, careful handling of soft tissues, irrigation, smoothing of sharp bone when necessary, and closure without excessive tension are commonly incorporated into preventive protocols (Ruggiero et al., 2022 & Munakata et al., 2025).

Primary closure is frequently recommended, particularly for higher-risk patients, but available evidence does not establish that it completely eliminates risk. Similarly, alveoplasty may be beneficial when sharp or irregular bone would interfere with mucosal healing, but extensive unnecessary removal of healthy bone should be avoided.

Antibiotics are commonly used around extraction in patients considered at increased risk, especially those receiving high-dose oncology therapy. However, the ideal antibiotic, timing, and duration remain uncertain. A 2025 scoping review demonstrated substantial heterogeneity among published protocols and concluded that patient risk category may be more important than any single universal antibiotic regimen (Munakata et al., 2025).

The decision to extract should therefore balance the biological consequences of persistent infection against the surgical risk. The presence of antiresorptive therapy alone should not automatically result in retention of a hopeless or chronically infected tooth.

Drug Holidays

Temporary interruption of antiresorptive therapy before dentoalveolar surgery remains one of the most controversial issues in MRONJ prevention. The biological rationale is that restoration of bone turnover might improve healing after surgery, but the pharmacology of implicated agents complicates this concept.

Bisphosphonates remain incorporated in bone for prolonged periods, meaning that interruption for a few weeks or months may have limited effect on local skeletal concentrations (Ruggiero et al., 2022). Denosumab, by contrast, does not accumulate within bone, and its biological effect gradually declines. However, stopping or substantially delaying denosumab in osteoporosis patients may provoke rebound skeletal turnover and increase the risk of vertebral fractures (Ruggiero et al., 2022 & Curtis et al., 2024).

A systematic review and meta-analysis examining antiresorptive drug holidays failed to demonstrate a statistically significant reduction in MRONJ following tooth extraction (Aboalela et al., 2022). Consequently, routine drug interruption for every patient cannot be recommended on the basis of current evidence.

International recommendations are not entirely uniform. AAOMS characterizes the evidence as inconclusive and favors individualized assessment (Ruggiero et al., 2022). The Italian position paper retains a more structured role for prophylactic drug holidays in selected circumstances, while recent Korean recommendations discuss medication-specific scheduling strategies (Bedogni et al., 2024 &Kim et al., 2025). These differences illustrate that drug interruption remains an area of professional disagreement rather than an established universal standard.

Any alteration of systemic therapy should therefore be discussed with the prescribing physician. The decision should incorporate medication type, treatment indication, dose, duration, cancer status, fracture risk, severity of dental infection, urgency of surgery, and available alternatives.

Management of Established MRONJ

The objectives of treatment are to relieve pain, control acute infection, limit progression, eliminate or stabilize necrotic bone, restore mucosal integrity when possible, preserve function, and maintain quality of life (Yarom et al., 2019 & Ruggiero et al., 2022).

Management should be individualized rather than determined solely by stage. The patient's systemic health, disease extent, prognosis, symptom burden, surgical fitness, and treatment preferences are highly relevant. A minimally symptomatic patient with limited stable disease may reasonably undergo conservative treatment, whereas a patient with recurrent infection and persistent necrotic bone may benefit from earlier definitive surgery.

Nonoperative Management

Nonoperative care typically involves meticulous oral hygiene, antimicrobial mouth rinses, analgesia, management of adjacent dental infection, and systemic antibiotics when symptomatic infection is present (Ruggiero et al., 2022).

Chlorhexidine is commonly used to reduce local microbial burden, particularly when exposed bone cannot be eliminated immediately. Antibiotics may be necessary for purulent drainage, cellulitis, or symptomatic infection, but they should not be regarded as definitive treatment for avascular or necrotic bone.

Repeated empirical antibiotic courses without reassessment should be avoided. Long-term antibiotic exposure may contribute to antimicrobial resistance and adverse effects while delaying appropriate surgery. Culture and susceptibility testing may be useful when infection is recurrent or refractory, especially after multiple previous antibiotic regimens.

Mobile sequestra may be allowed to exfoliate spontaneously or may be removed with limited trauma. Sharp bony edges that repeatedly traumatize adjacent mucosa may be conservatively smoothed.

Nonoperative therapy remains appropriate for selected patients, particularly those with limited symptoms, significant comorbidities, poor oncological prognosis, or reluctance to undergo surgery. A 2025 retrospective analysis demonstrated that some patients can achieve favorable outcomes with nonoperative management, supporting continued use of conservative care in carefully selected circumstances (Seluki et al., 2023).

Surgical Management

The role of surgery in MRONJ has expanded considerably. Earlier approaches frequently reserved extensive surgery for Stage 3 disease or persistent lesions that had failed conservative care. Contemporary evidence increasingly suggests that operative treatment can result in high rates of disease control and mucosal healing even in selected earlier-stage cases (Giudice et al., 2020 & Ruggiero et al., 2022 & Wei et al., 2025).

The systematic literature generally favors surgery when disease is symptomatic, progressive, or associated with persistent necrotic bone. A 2023 systematic review comparing conservative

and surgical treatment concluded that surgery appears superior in more advanced disease, while conservative approaches remain reasonable for asymptomatic early lesions (Zigmantavičius et al., 2022).

The extent of surgery ranges from limited sequestrectomy to debridement, marginal resection, and segmental resection. Limited sequestrectomy may be sufficient when necrotic bone is clearly demarcated and separated from viable tissue. More extensive disease may require removal of surrounding abnormal bone to achieve a viable margin.

Surgical planning should incorporate three-dimensional imaging because the clinically exposed lesion may underestimate the true extent of osseous involvement. CBCT or CT can reveal diffuse sclerosis, cortical perforation, sequestration, mandibular canal involvement, sinus extension, and regions at risk of fracture (Ko et al., 2024 & Yarom et al., 2025).

In advanced mandibular disease, segmental resection may be necessary when necrosis reaches the inferior border or when pathological fracture is present. Maxillary disease may require removal of necrotic bone together with management of associated sinus pathology and reliable closure of oroantral defects.

Recent systematic reviews confirm that surgical treatment achieves favorable results across a range of techniques, although heterogeneity in definitions of healing and treatment protocols makes direct comparison difficult (Wei et al., 2025).

Reconstruction

Extensive MRONJ surgery may create clinically significant osseous and soft-tissue defects. Reconstruction must be individualized according to the location and size of the defect, general health, oncological prognosis, previous therapies, and expected functional benefit.

Small defects may be managed with local mucosal advancement or regional tissue. In the maxilla, the buccal fat pad can provide useful vascularized coverage for selected posterior defects. Advanced mandibular disease may require load-bearing reconstruction plates or vascularized osseous free flaps when restoration of continuity is necessary.

Microvascular reconstruction can provide reliable bone and soft tissue in carefully selected patients, but the procedure must be justified by functional needs and systemic prognosis. The decision is particularly complex in patients with metastatic malignancy, in whom extensive reconstructive surgery must be balanced against disease burden and life expectancy.

Autologous Platelet Concentrates

Autologous platelet concentrates have received considerable attention as adjunctive treatments because they provide fibrin matrices containing platelets, leukocytes, cytokines, and growth factors that may support angiogenesis and tissue repair.

Platelet-rich fibrin and related preparations have been used both during dentoalveolar surgery in at-risk patients and after surgical removal of established MRONJ lesions. A 2024 systematic review and meta-analysis found a potential preventive benefit but

emphasized that the certainty of evidence was limited by heterogeneity and risk of bias (Nowak et al., 2024). A 2025 systematic review similarly concluded that platelet concentrates may improve healing when used as adjuncts but that standardized protocols and stronger comparative trials are still needed (Ferreira et al., 2025).

Accordingly, platelet concentrates should not replace adequate removal of necrotic tissue, infection control, or tension-free soft-tissue closure. Their current role is best regarded as adjunctive.

Photobiomodulation

Photobiomodulation has been investigated as a supportive approach because low-level light exposure may modulate inflammation, promote cellular metabolism, support angiogenesis, and improve wound healing.

Clinical protocols vary widely in wavelength, energy density, duration, number of sessions, and combination with other treatments. Some studies have reported improvement in pain, mucosal healing, and lesion resolution, particularly when photobiomodulation is combined with surgery or platelet concentrates.

A 2025 systematic review concluded that photobiomodulation may reduce MRONJ occurrence after extraction and may improve outcomes in established disease, but the authors emphasized the heterogeneity of treatment protocols and the need for stronger controlled trials (Mahintach et al., 2025). A separate 2024 systematic evaluation similarly reported promising effects on pain and healing but insufficient evidence for universal treatment parameters (Benetti et al., 2024).

Photobiomodulation should therefore be considered a potentially useful adjunct rather than an established replacement for conventional management.

Other Adjunctive Therapies

Several additional interventions have been investigated, including hyperbaric oxygen, teriparatide, pentoxifylline with tocopherol, ozone therapy, tissue-engineering approaches, and locally delivered regenerative agents.

Hyperbaric oxygen has theoretical benefits related to oxygenation and angiogenesis, but evidence remains insufficient to recommend routine use. Teriparatide may stimulate bone remodeling and has shown potential benefit in selected osteoporosis-associated cases, although it is not appropriate for every patient and requires careful consideration of systemic contraindications.

Pentoxifylline and tocopherol have been more extensively studied in osteoradionecrosis and have also been explored in MRONJ. The available evidence remains limited and heterogeneous. Ozone therapy similarly has proposed antimicrobial and wound-healing effects but lacks sufficiently robust controlled evidence to justify universal use.

Emerging regenerative strategies involving stem cells, biological scaffolds, growth factors, bone morphogenetic proteins, and local drug-delivery systems remain primarily investigational. A recent network meta-analysis suggested that some adjunctive combinations may improve outcomes, but many comparisons were indirect and were based on relatively small studies (Beth-Tasdogan et al., 2022).

Antibiotic Therapy and Antimicrobial Stewardship

Antibiotics remain important in the management of symptomatic MRONJ when active infection is present. Their role is principally to control bacterial infection and associated soft-tissue inflammation rather than to reverse the underlying necrotic process.

The choice of antibiotic should be guided by severity of infection, allergy history, previous exposure, renal function, and local resistance patterns. Prolonged or repeated empirical therapy should be avoided because it can promote resistance and expose patients to unnecessary adverse effects.

The preventive use of antibiotics around tooth extraction is common, but protocols differ substantially between institutions. Current literature has not identified a universally superior regimen. The recent scoping review of antibiotic prophylaxis and postoperative treatment demonstrated marked variation in drug selection and duration and reinforced the need for individualized risk-based prescribing (Munakata et al., 2025).

Antimicrobial stewardship is therefore an important component of MRONJ care. Antibiotics should be used when there is a clear clinical indication rather than simply because exposed bone is present.

MRONJ in Osteoporosis Patients

The management of osteoporosis patients requires careful communication because the absolute risk of MRONJ is relatively low compared with the potential consequences of untreated skeletal fragility (Ruggiero et al., 2022).

Routine dental treatment should generally continue without unnecessary modification. Restorative procedures, periodontal maintenance, and nonsurgical endodontic treatment can usually be provided without interruption of antiresorptive therapy.

When invasive surgery is required, risk assessment should include treatment duration, medication type, systemic comorbidities, local inflammation, and the complexity of the procedure. The presence of low-dose antiresorptive therapy does not automatically contraindicate extraction.

Denosumab requires particular caution because prolonged postponement or discontinuation can cause rebound bone loss. Any modification of dosing should be coordinated with the prescribing clinician (Ruggiero et al., 2022 & Curtis et al., 2024).

MRONJ in Oncology Patients

Patients receiving high-dose antiresorptive therapy for malignancy represent a distinctly higher-risk group. Comprehensive dental assessment before initiation of treatment is therefore particularly important.

During active oncological antiresorptive treatment, unnecessary elective dentoalveolar procedures should be minimized when reasonable alternatives exist. Nevertheless, persistent odontogenic infection must not be ignored because chronic inflammation may itself contribute to MRONJ development.

Management decisions should incorporate cancer status, skeletal disease burden, life expectancy, chemotherapy or immunotherapy, hematological parameters, nutritional condition, and the consequences of altering systemic treatment.

Communication with the oncology team is essential. Dental clinicians should provide clear information regarding the nature and urgency of the oral disease, while the oncology team should clarify the importance of continuing or modifying systemic therapy.

Quality of Life

MRONJ can substantially affect quality of life. Pain, recurrent infection, halitosis, impaired mastication, difficulty wearing prostheses, altered appearance, and repeated clinical visits may impose a significant psychological and functional burden (Murphy & Mannion, 2020).

The impact of disease should therefore influence treatment selection. A patient with persistent Stage 2 disease who requires repeated antibiotics and experiences recurrent pain may benefit more from definitive surgery than from indefinite conservative treatment, even if disease is not anatomically extensive.

Conversely, aggressive surgery may not be appropriate in a medically frail patient with minimal symptoms and limited life expectancy. Management should therefore consider not only anatomical staging but also functional impairment, symptom burden, and personal treatment priorities.

Prognosis

The prognosis of MRONJ varies according to medication exposure, systemic condition, disease stage, anatomical extent, local infection, and treatment strategy.

A 2025 systematic review and meta-analysis examining prognostic indicators identified multiple medication-related, lesion-

related, systemic, and treatment-related variables associated with outcome (Misiejuk et al., 2026). Surgical management emerged as an important determinant of complete healing in appropriately selected cases, although heterogeneity among studies remains substantial.

Extent of disease also influences outcome. Diffuse lesions involving the inferior mandibular border or adjacent anatomical spaces are more difficult to treat than small localized sequestra.

Adequacy of resection may be important because residual nonviable bone can contribute to recurrence. Nevertheless, overly extensive surgery should be avoided when it produces unnecessary morbidity without clear therapeutic benefit.

Long-term follow-up remains necessary because recurrence can occur even after apparent complete mucosal healing.

Follow-Up

Follow-up should focus on symptoms, mucosal integrity, recurrent bone exposure, swelling, fistulation, drainage, tooth and implant status, neurosensory changes, and oral hygiene.

Imaging should be repeated when the clinical course changes or when there is concern regarding progression, sequestration, recurrence, or surgical planning. Routine repeated three-dimensional imaging without a clinical indication is generally unnecessary (Yarom et al., 2025).

Patients who have successfully healed should continue regular preventive dental care because antiresorptive exposure and

systemic risk factors may persist, and new lesions can occur at other sites.

Multidisciplinary Care

Effective MRONJ care requires communication between dentistry, oral and maxillofacial surgery, oncology, endocrinology, hematology, rheumatology, radiology, and primary care.

The medication history should identify the exact agent, indication, dose, route, frequency, duration, and previous antiresorptive exposure. Concomitant therapies such as corticosteroids, chemotherapy, immunotherapy, and antiangiogenic medications should also be documented.

When invasive treatment or alteration of systemic therapy is being considered, communication with the prescribing clinician is essential. The dental team should explain the oral diagnosis, treatment alternatives, urgency, and expected healing requirements. The medical team should clarify the consequences of delaying or interrupting systemic therapy.

Shared decision-making helps prevent two opposing errors: inappropriate discontinuation of beneficial systemic treatment and inappropriate avoidance of necessary dental care.

Future Perspectives

Despite substantial advances, several important questions remain unresolved. No biomarker currently provides reliable individualized prediction of MRONJ, and the ideal strategy for timing surgery around antiresorptive treatment remains uncertain.

Three-dimensional imaging is likely to play an increasing role in quantification of disease. CBCT-based radiomics, fractal analysis, and artificial intelligence are being investigated as potential tools for identifying early structural changes and estimating prognosis. A 2026 systematic review of quantitative fractal analysis illustrates the growing interest in objective imaging biomarkers, although their clinical value remains under investigation (Rosella et al., 2016).

Artificial intelligence may also assist lesion detection and segmentation, but these technologies require external validation and prospective testing before routine use.

Future clinical trials should adopt standardized definitions of complete healing, partial response, progression, and recurrence. Better stratification according to medication class, dose, treatment indication, oral inflammatory burden, and disease stage will be necessary to determine which patients benefit most from early surgery or adjunctive approaches.

Conclusion

Medication-related osteonecrosis of the jaw is a complex and multifactorial complication that develops through interaction between pharmacological suppression of bone remodeling, local inflammatory disease, microbial exposure, impaired healing, and systemic susceptibility.

The risk differs substantially between low-dose osteoporosis treatment and high-dose oncological antiresorptive therapy. This distinction is fundamental to patient counseling and treatment planning.

Prevention remains the cornerstone of management. Dental assessment before high-risk therapy, treatment of active periodontal and periapical disease, maintenance of oral hygiene, control of prosthetic trauma, and regular follow-up can reduce the likelihood that invasive procedures will become necessary during treatment.

MRONJ remains predominantly a clinical diagnosis, but three-dimensional imaging has become increasingly important for determining disease extent and planning treatment (Ko et al., 2024 & Yarom et al., 2025).

The role of surgery has expanded. Contemporary evidence indicates that appropriately selected surgical treatment may achieve favorable outcomes not only in advanced disease but also in selected earlier-stage lesions. Nevertheless, conservative management remains appropriate in asymptomatic or medically compromised patients, and treatment decisions should remain individualized (Zigmantavičius et al., 2022 & Ruggiero et al., 2022).

Routine drug holidays cannot currently be recommended because evidence of benefit is inconsistent and medication interruption may create significant systemic risk (Ruggiero et al., 2022 & Aboalela et al., 2022). Adjunctive strategies such as autologous platelet concentrates and photobiomodulation remain promising but should currently complement rather than replace established preventive and surgical principles (Nowak et al., 2024 & Aljohani et al., 2024).

Ultimately, successful MRONJ management depends on patient-centered multidisciplinary care that balances oral disease control with the essential systemic benefits of antiresorptive and oncological therapies.

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CHAPTER 2

Minimally Invasive Techniques in Oral and Maxillofacial Surgery

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Introduction

Minimally invasive surgery has become one of the most important contemporary concepts in oral and maxillofacial surgery because of increasing emphasis on reduced surgical morbidity, faster recovery, improved patient comfort, and preservation of anatomical structures (Ellis & Zide, 2006).

Traditional maxillofacial surgical approaches often required extensive flap elevation, large incisions, prolonged operative times, and significant postoperative morbidity (Hupp et al., 2019). Although these techniques remain necessary in many complex conditions, technological advances have facilitated development of

less invasive alternatives capable of achieving comparable clinical outcomes with reduced tissue trauma.

Minimally invasive approaches aim to minimize surgical injury while maintaining procedural effectiveness and predictability (Hunter, 1999). In oral and maxillofacial surgery, these techniques increasingly include piezosurgery, endoscopic procedures, flapless implant placement, computer-guided surgery, minimally invasive bone harvesting, arthroscopy, navigation-assisted surgery, and robotic-assisted interventions.

The growing integration of digital imaging, cone-beam computed tomography, intraoral scanning, CAD/CAM systems, and three-dimensional planning technologies has substantially accelerated adoption of minimally invasive workflows (Bell, 2010).

Patient demand for shorter recovery times, reduced postoperative pain, improved aesthetics, and lower complication rates has additionally contributed to widespread interest in minimally invasive surgery (Vercellotti, 2007).

Preservation of vascularity, reduction of soft tissue trauma, decreased edema, and maintenance of anatomical integrity represent major biological advantages of minimally invasive approaches (Wallace et al., 2007).

Minimally invasive techniques are now applied in numerous oral and maxillofacial procedures including implant surgery, sinus augmentation, temporomandibular joint surgery, orthognathic surgery, cyst removal, fracture management, reconstructive surgery, and dentoalveolar procedures (McCain, 1996).

Piezosurgery has become particularly important because ultrasonic bone cutting allows selective mineralized tissue removal while minimizing damage to adjacent soft tissues such as nerves, vessels, and mucosa (Vercellotti, 2004).

Endoscopic techniques additionally permit improved visualization through smaller surgical access points and reduced soft tissue dissection(Troulis& Kaban, 2001).

Flapless implant surgery and computer-guided implant placement have also gained popularity because of reduced surgical morbidity and improved patient-centered outcomes (Fortin et al., 2006).

Despite substantial advantages, minimally invasive approaches are not universally applicable and may involve limitations including increased technical complexity, learning curves, equipment costs, and restricted visibility in selected cases (D'haese et al., 2017).

This chapter reviews the principles, biological rationale, clinical applications, advantages, limitations, and future perspectives of minimally invasive techniques in oral and maxillofacial surgery.

Biological Principles of Minimally Invasive Surgery

The primary biological objective of minimally invasive surgery is reduction of tissue trauma while preserving vascular supply, anatomical structures, and physiological healing capacity (Frost, 1989).

Extensive surgical dissection may impair blood supply, increase inflammatory response, prolong edema, and delay tissue

healing (Dimitriou et al., 2011). Minimally invasive approaches attempt to reduce these negative effects through smaller incisions, limited flap elevation, and precise tissue manipulation.

Preservation of periosteal vascularity is particularly important in oral and maxillofacial surgery because periosteal blood supply contributes significantly to bone vitality and postoperative regeneration (Misch, 1997).

Reduced surgical trauma is additionally associated with lower postoperative cytokine release and diminished inflammatory response (Kehlet, 1997). Patients therefore often experience reduced pain, swelling, trismus, and functional limitation.

Maintenance of soft tissue integrity may also improve aesthetic outcomes and reduce scar formation (Mustoe, 2002).

In implant surgery, minimally invasive approaches may preserve papillary architecture and peri-implant soft tissue stability while reducing crestal bone remodeling (Oh et al., 2006).

Improved preservation of anatomical structures such as nerves, sinus membranes, and vascular networks represents another major advantage of minimally invasive surgery (Eggers et al., 2004).

The biological benefits of minimally invasive procedures therefore contribute directly to improved postoperative recovery and patient satisfaction.

Piezosurgery

Piezosurgery represents one of the most important technological advances in minimally invasive oral surgery (Vercellotti & Pollack, 2006). The technique utilizes ultrasonic

microvibrations for selective cutting of mineralized tissues while minimizing injury to adjacent soft tissues.

Piezoelectric devices operate through modulated ultrasonic frequencies generally ranging between 25 and 35 kHz (Horton et al., 1975). At these frequencies, mineralized tissues may be cut efficiently while nerves, blood vessels, and soft tissues remain relatively protected.

Selective cutting ability represents one of the major advantages of piezosurgery compared with conventional rotary instruments and oscillating saws (Stubingeret al., 2005).

Another important feature involves cavitation effects generated during ultrasonic vibration. Cavitation improves surgical visibility through continuous irrigation and reduction of intraoperative bleeding (Pavlikova et al., 2011).

Piezosurgery is now widely used in numerous oral and maxillofacial procedures including:

- tooth extraction,
- sinus augmentation,
- ridge splitting,
- bone harvesting,
- orthognathic surgery,
- nerve lateralization,
- cystectomy,
- osteotomy procedures (Robiony et al., 2004).

In implant surgery, piezosurgery may reduce thermal bone injury and improve precision during osteotomy preparation (Preti et al., 2007).

Several studies have demonstrated reduced postoperative pain, swelling, and neurosensory complications associated with piezoelectric surgery compared with conventional rotary instrumentation (Barone et al., 2010).

Piezosurgery is particularly advantageous in procedures involving close proximity to delicate anatomical structures such as the inferior alveolar nerve or Schneiderian membrane (Wallace & Froum, 2007).

Despite these benefits, piezosurgery generally requires longer operative times and greater surgical experience (Landes et al., 2008). High equipment cost may additionally limit accessibility in some clinical settings.

Nevertheless, piezoelectric surgery continues to gain widespread acceptance because of its precision, safety profile, and minimally invasive characteristics.

Flapless Implant Surgery

Flapless implant surgery has become increasingly popular as a minimally invasive alternative to conventional implant placement techniques (Becker et al., 2006).

Traditional implant surgery generally involves mucoperiosteal flap elevation to provide direct visualization of alveolar bone (Misch, 2008). Although effective, flap elevation may compromise blood supply, increase crestal bone remodeling, and contribute to postoperative discomfort.

Flapless implant placement aims to preserve periosteal vascularity and minimize soft tissue trauma by avoiding flap reflection (Jeong et al., 2007).

Potential advantages include reduced surgical time, diminished postoperative pain and edema, faster healing, preservation of papillary architecture, and improved patient comfort (Campelo & Camara, 2002).

Flapless approaches may be performed using soft tissue punches, tissue-guided drilling, or computer-guided surgical templates (Fortin et al., 2002).

Successful flapless surgery depends heavily on accurate preoperative imaging and careful case selection because direct visualization of anatomical structures is limited (Rousseau, 2010).

Cone-beam computed tomography plays a central role in flapless implant planning because precise evaluation of bone volume, angulation, and anatomical limitations is essential (Jacobs & Quirynen, 2000).

Computer-guided surgery has significantly improved the safety and predictability of flapless implant placement (Vercruyssen et al., 2014).

However, flapless procedures may involve limitations including inability to visualize bone defects, limited capacity for simultaneous augmentation procedures, and increased risk of malpositioning in inexperienced hands (Brodala, 2009).

Careful patient selection therefore remains essential for predictable outcomes.

Computer-Guided Implant Surgery

Computer-guided implant surgery represents one of the most important developments in minimally invasive implant dentistry (Tahmaseb et al., 2014).

Guided surgery integrates CBCT imaging, digital impressions, virtual planning software, and CAD/CAM-generated surgical templates to facilitate accurate implant positioning (Ganz, 2011).

Digital workflows permit prosthetically driven planning based on anatomical conditions, occlusion, aesthetic requirements, and restorative design (Joda & Gallucci, 2015).

Static guided surgery utilizes prefabricated surgical templates directing drilling angulation and implant positioning during surgery (D'haese et al., 2014).

Dynamic navigation systems provide real-time tracking of surgical instrumentation and anatomical structures during implant placement (Block & Emery, 2016).

Guided surgery may improve implant positioning accuracy, reduce surgical trauma, minimize flap size, shorten operative time, and facilitate flapless procedures (Schneider et al., 2009).

Several studies have reported improved patient-centered outcomes including reduced postoperative pain and swelling associated with guided implant surgery (Pozzi et al., 2014).

Guided workflows may additionally improve safety in anatomically challenging cases involving limited bone volume or proximity to vital structures (Van Assche et al., 2007).

Despite these advantages, guided surgery may involve technical complications including template instability, registration errors, restricted irrigation, and cumulative digital inaccuracies (Tahmaseb et al., 2014).

High equipment costs and learning curves also remain important limitations.

Nevertheless, computer-guided surgery continues to expand rapidly as digital implant workflows become increasingly integrated into modern clinical practice.

Endoscopic Techniques in Oral and Maxillofacial Surgery

Endoscopic surgery represents another major component of minimally invasive maxillofacial procedures because it permits improved visualization through smaller incisions and reduced soft tissue dissection (Troulis& Kaban, 2001).

Endoscopic systems utilize fiberoptic or digital camera technologies combined with specialized surgical instruments to access anatomical regions through limited surgical entry points (Schmelzeisen et al., 2000).

In oral and maxillofacial surgery, endoscopic techniques are increasingly applied in temporomandibular joint surgery, fracture management, sinus surgery, salivary gland procedures, orthognathic surgery, and reconstructive interventions (Kellman & Marentette, 2000).

Temporomandibular joint arthroscopy is among the most established endoscopic procedures in maxillofacial surgery (McCain, 1988). Arthroscopic approaches permit diagnosis and treatment of internal derangements, adhesions, inflammatory conditions, and joint dysfunction through minimally invasive portals.

Advantages of TMJ arthroscopy include reduced postoperative morbidity, shorter hospitalization, diminished scar formation, and faster recovery compared with open joint surgery (Murakamiet al., 1996).

Endoscope-assisted fracture management has also gained popularity, particularly in mandibular condyle fractures (Schön et al., 2002). Endoscopic visualization permits fracture reduction and fixation through smaller incisions while minimizing facial nerve injury risk and external scarring.

Endoscopic sinus augmentation procedures may additionally reduce membrane perforation risk and improve visualization during Schneiderian membrane elevation (Felisati et al., 2010).

Salivary gland endoscopy, or sialendoscopy, represents another important minimally invasive application (Marchal et al., 2003). This technique permits diagnosis and treatment of ductal obstructions, strictures, and sialolithiasis while preserving glandular tissue.

Endoscopic techniques generally provide superior illumination and magnification compared with direct visualization alone (Troulis et al., 2002).

However, limitations include restricted instrument maneuverability, longer learning curves, equipment costs, and technical complexity (Schmelzeisen et al., 2001).

Despite these challenges, continued technological refinement is expected to further expand endoscopic applications in oral and maxillofacial surgery.

Minimally Invasive Bone Harvesting Techniques

Autogenous bone grafting remains an essential component of reconstructive oral surgery; however, traditional bone harvesting procedures may produce significant donor site morbidity (Nkenke & Neukam, 2014).

Minimally invasive bone harvesting techniques therefore aim to reduce surgical trauma, postoperative pain, neurosensory complications, and functional impairment.

Piezosurgery has become particularly valuable during bone harvesting because selective cutting minimizes soft tissue injury and reduces thermal trauma (Vercellotti et al., 2001).

Trephine-based harvesting systems may additionally permit procurement of particulate bone grafts through relatively small access sites (Khoury & Hanser, 2015).

Bone scrapers represent another minimally invasive option for collection of autogenous cortical bone particles during implant site preparation or ridge augmentation (Safi et al., 2017).

Intraoral donor sites including mandibular ramus and symphysis are frequently preferred because they reduce hospitalization and avoid extraoral morbidity (Misch, 1997).

Endoscopic-assisted harvesting techniques have also been investigated to further minimize donor site trauma and improve visualization (Zemann et al., 2001).

Minimally invasive harvesting methods may reduce postoperative edema, pain, and sensory disturbances while maintaining adequate graft quality (Raghoebar et al., 2001).

Nevertheless, large-volume defects may still require conventional harvesting approaches or vascularized free flaps.

Minimally Invasive Sinus Augmentation Procedures

Maxillary sinus augmentation is commonly performed to facilitate implant placement in the atrophic posterior maxilla (Jensen, 2006).

Traditional lateral window sinus surgery generally requires extensive flap elevation and large osteotomy preparation (Boyne & James, 1980).

Minimally invasive alternatives including transcrestal sinus elevation techniques have therefore gained increasing popularity.

The osteotome sinus floor elevation technique introduced by Summers represented one of the earliest minimally invasive sinus augmentation approaches (Summers, 1994).

Subsequent modifications incorporating hydraulic pressure, balloon elevation systems, piezosurgery, and endoscopic assistance have further improved procedural safety and predictability(Sotirakis & Gonshor, 2005).

Piezoelectric devices are especially advantageous in sinus surgery because they permit precise osteotomy preparation while reducing Schneiderian membrane perforation risk (Wallace et al., 2007).

Endoscopic visualization may additionally facilitate direct observation of membrane elevation and early identification of complications (Engelke & Deckwer, 1997).

Minimally invasive sinus augmentation techniques generally demonstrate reduced postoperative morbidity, shorter recovery periods, and improved patient comfort compared with traditional lateral window procedures (Del Fabbro et al., 2013).

However, careful case selection remains essential because severe maxillary atrophy may still require conventional lateral approaches.

Arthroscopy and Minimally Invasive TMJ Surgery

Temporomandibular joint surgery has evolved substantially toward minimally invasive approaches during recent decades (Dimitroulis, 1998).

Arthrocentesis and arthroscopy are now widely accepted as first-line surgical interventions for many TMJ disorders because of reduced morbidity compared with open joint surgery (Al-Moraissi et al., 2020).

Arthrocentesis involves lavage of the superior joint space using irrigation needles and may improve joint mobility by eliminating inflammatory mediators and releasing adhesions (Nitzan et al., 1991).

TMJ arthroscopy provides direct visualization of intra-articular structures while permitting minimally invasive operative procedures including adhesion release, lavage, biopsy, and disc manipulation (McCain, 1996).

These procedures generally produce reduced postoperative pain, minimal scarring, shorter hospitalization, and faster functional recovery (Murakami et al., 1995).

Arthroscopy may additionally delay or prevent the need for open surgical intervention in selected patients (Dimitroulis, 2005).

Although open surgery remains necessary for severe structural pathology, minimally invasive TMJ procedures now represent central components of contemporary management strategies.

Navigation-Assisted Surgery

Computer-assisted navigation systems are increasingly integrated into minimally invasive maxillofacial surgery because they improve intraoperative anatomical orientation and surgical precision (Ewers et al., 2005).

Navigation systems utilize preoperative imaging datasets combined with real-time instrument tracking to guide surgical procedures (Gellrich et al., 2002).

Applications include implant placement, orthognathic surgery, tumor resection, orbital reconstruction, and craniofacial trauma management (Bell, 2010).

Navigation-assisted surgery may improve accuracy while minimizing unnecessary dissection and reducing risk of injury to critical anatomical structures (Widmann & Bale, 2006).

The technology is particularly valuable in anatomically complex regions where direct visualization is limited.

Combination of navigation systems with endoscopic techniques may further enhance minimally invasive surgical precision (Schramm et al., 1999).

Despite significant advantages, high equipment cost and technical complexity continue to limit widespread routine use.

Robotic Surgery in Maxillofacial Procedures

Robotic-assisted surgery represents an emerging field within minimally invasive oral and maxillofacial surgery (Weinstein et al., 2007).

Robotic systems provide enhanced dexterity, tremor reduction, magnified visualization, and improved instrument precision (O'Malley & Weinstein, 2007).

Transoral robotic surgery has demonstrated increasing utility in head and neck oncology procedures because it permits access to difficult anatomical regions without extensive external incisions (Moore et al., 2009).

Potential future applications in implant dentistry and reconstructive surgery include robotic-assisted osteotomies, implant placement, and microsurgical procedures (Yang et al., 2021).

However, current limitations include high cost, limited availability, prolonged setup time, and steep learning curves (Lanfranco et al., 2004).

Although still relatively limited in oral surgery, robotic technologies are expected to expand substantially in future minimally invasive workflows.

Advantages of Minimally Invasive Surgery

Minimally invasive techniques provide numerous biological, functional, and patient-centered advantages in oral and maxillofacial surgery (Kehlet & Wilmore, 2002).

Reduced surgical trauma is one of the most important benefits because limited dissection and preservation of vascular supply may significantly decrease postoperative inflammation and tissue damage (Hunter, 1999).

Patients frequently experience reduced postoperative pain, swelling, ecchymosis, and trismus compared with conventional surgical approaches (Barone et al., 2010).

Shorter operative times and faster healing may additionally improve patient comfort and reduce hospitalization requirements (Kehlet, 2008).

Preservation of soft tissue integrity may contribute to improved aesthetic outcomes and reduced scar formation, particularly in facial procedures (Mustoe, 2002).

Minimally invasive implant surgery may additionally preserve papillary architecture and crestal bone stability while improving postoperative comfort (Jeong et al., 2007).

Endoscopic and navigation-assisted procedures often permit superior magnification and illumination, potentially improving surgical precision and reducing risk of injury to adjacent anatomical structures (Eggers et al., 2004).

Reduced morbidity may be especially advantageous in medically compromised or elderly patients with limited physiological reserve (Marchini & Ettinger, 2014).

Improved patient acceptance and satisfaction additionally contribute to increasing popularity of minimally invasive surgical approaches.

Limitations and Challenges

Despite substantial advantages, minimally invasive techniques also present important limitations and challenges (Brodala, 2009).

One of the primary concerns involves restricted surgical visibility and limited direct access to anatomical structures (Rousseau, 2010). Inadequate visualization may increase procedural difficulty and risk of complications in inexperienced hands.

Many minimally invasive procedures require advanced technical skills and prolonged learning curves (Tahmaseb et al., 2014). Surgical experience therefore remains critically important for predictable outcomes.

High equipment costs represent another important limitation. Piezoelectric devices, endoscopic systems, navigation technologies, and robotic platforms may require substantial financial investment (Landes et al., 2008).

Digital workflows additionally depend on accurate imaging, software integration, and technical calibration. Errors in data acquisition or template fabrication may compromise surgical accuracy (Vercruyssen et al., 2014).

Minimally invasive approaches may also be unsuitable for extensive pathology, severe anatomical deformities, or advanced reconstructive procedures requiring broad surgical exposure (Ellis & Zide, 2006).

Flapless implant surgery, for example, may increase risk of implant malpositioning or inadequate management of underlying bone defects when case selection is inappropriate (Oh et al., 2006).

Careful patient evaluation and appropriate procedural selection therefore remain essential.

Future Perspectives

The future of minimally invasive oral and maxillofacial surgery is expected to involve increasing integration of digital technologies, artificial intelligence, robotics, navigation systems, and regenerative medicine (Bell, 2010).

Artificial intelligence-assisted planning systems may improve surgical accuracy through automated anatomical analysis and individualized treatment recommendations (Schwendicke et al., 2020).

Augmented reality and mixed reality technologies may additionally enhance intraoperative visualization and real-time surgical guidance (Mischkowski et al., 2006).

Robotic-assisted surgery is likely to expand further as systems become more precise, accessible, and adaptable to maxillofacial procedures (Yang et al., 2021).

Three-dimensional printing technologies and patient-specific surgical guides may continue improving minimally invasive reconstructive approaches (Mazzoni et al., 2015).

Regenerative medicine and biologically active biomaterials may further reduce the need for extensive surgical intervention by improving healing and tissue preservation (O'Brien, 2011).

Continued technological advancement is expected to improve procedural safety, precision, efficiency, and patient-centered outcomes.

Conclusion

Minimally invasive techniques have fundamentally transformed contemporary oral and maxillofacial surgery by reducing surgical morbidity while maintaining clinical effectiveness and predictability.

Technologies such as piezosurgery, endoscopic surgery, flapless implant placement, computer-guided surgery, navigation systems, and robotic-assisted procedures now play increasingly important roles across numerous surgical applications.

These approaches may reduce postoperative pain, swelling, scarring, and recovery time while improving preservation of vascularity and anatomical structures.

Digital workflows integrating CBCT imaging, CAD/CAM systems, surgical navigation, and three-dimensional planning have substantially accelerated adoption of minimally invasive procedures.

Despite considerable advantages, minimally invasive surgery also involves important limitations including technical complexity, equipment costs, restricted visualization, and learning curve challenges.

Appropriate case selection, comprehensive training, and careful surgical planning remain essential for predictable outcomes.

Future developments involving artificial intelligence, augmented reality, robotics, regenerative medicine, and advanced digital technologies are expected to further expand the role of minimally invasive approaches in oral and maxillofacial surgery.

Overall, minimally invasive surgery represents a major paradigm shift toward safer, more precise, biologically respectful, and patient-centered maxillofacial treatment strategies.

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CHAPTER 3

Medication-Related Osteonecrosis of the Jaw (MRONJ): Current Approaches, Prevention and Surgical Treatment

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Introduction

Medication-related osteonecrosis of the jaw (MRONJ) requires local disease control without unnecessarily compromising systemic bone-modifying treatment. The objectives are durable healing, control of pain and infection, and preservation of oral function. The oncology-specific MASCC/ISOO/ASCO guideline established dental optimization and coordinated care as foundations of management. Its conservative initial approach must be interpreted alongside subsequent evidence supporting selected operative treatment (Yarom et al., 2019).

The clinical framework integrates anatomical disease burden, healing capacity and patient priorities. Stage provides a common language but cannot determine the operation without cross-sectional assessment. Similarly, mucosal closure is an important endpoint

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without necessarily demonstrating complete resolution of the underlying osseous process.

Biological basis and medication exposure

MRONJ reflects suppressed remodeling interacting with inflammation and impaired repair. Bisphosphonates accumulate in mineralized tissue and inhibit osteoclast function; denosumab inhibits receptor activator of nuclear factor κB ligand without equivalent skeletal retention. These differences preclude identical interruption schedules. Angiogenic, mucosal, immune and lymphatic disturbances may contribute. Frequent microbial challenge and remodeling demands make tooth-bearing jaws vulnerable; a nonhealing socket does not establish extraction as the sole cause (Bassan Marinho Maciel et al., 2024).

Microorganisms perpetuate inflammation within poorly vascularized necrotic bone. Culture and molecular analyses demonstrate complex anaerobic communities, including Actinomyces and related organisms. Detection should inform specimen handling and clinically indicated antimicrobial selection without implying a single-organism cause. Deep operative specimens are more informative than superficial swabs; histology, clinical infection and prior antibiotic exposure help distinguish colonization from invasive disease (Kövér et al., 2025).

Record medication indication, dose, interval, cumulative exposure, prior agents and recent administration dates. “Intravenous therapy” and “cancer patient” are inadequate categories. Low-dose treatment for endocrine therapy-associated bone loss differs from high-dose treatment for metastases, a distinction emphasized by the 2025 SIPMO–SIOMMMS report. Glucocorticoids, antiangiogenic therapy, diabetes, nutritional compromise and smoking further modify assessment (Bertoldo et al., 2025).

Risk estimation and communication

Explain absolute risk with its denominator and observation period. A UK cohort of women treated predominantly with alendronate reported 1.2 cases per 10,000 person-years during current treatment, with approximately 0.05% cumulative risk at five years. These estimates support balanced osteoporosis counseling but are neither post-extraction probabilities nor applicable to high-dose oncology treatment (Persson et al., 2025).

A metastatic-cancer cohort receiving denosumab reported cumulative MRONJ incidence of 5.7% at 24 months and 9.8% at 48 months, accounting for competing mortality. Dental procedures were associated with risk, although underlying dental disease complicates causal interpretation. Intensify surveillance and discuss the consequences of untreated infection and withheld systemic treatment alongside procedural risk (Bracchi et al., 2023).

Diagnosis and clinical staging

Under the AAOMS framework, diagnosis requires current or previous antiresorptive treatment, alone or combined with immune-modulating or antiangiogenic medication; exposed bone or bone probeable through a fistula in the maxillofacial region persisting for more than eight weeks; and no history of jaw irradiation or jaw metastasis. Stage 1 describes exposed or probeable necrotic bone without symptoms or infection. Stage 2 adds symptomatic infection or inflammation. Stage 3 comprises exposed or probeable infected necrotic bone with advanced extension, pathological fracture, extraoral fistula, oroantral or oronasal communication, or osteolysis reaching the mandibular inferior border or sinus floor. Stage 0 denotes a non-exposed presentation with nonspecific clinical or radiographic abnormalities and requires careful exclusion of competing diagnoses. AAOMS also recognizes operative treatment

as an option across stages; stage alone does not impose mandatory prolonged observation (Ruggiero et al., 2022).

Examination should map exposure and fistulae, identify mobile sequestra and sensory change, and assess periodontal, periapical and peri-implant disease. Probe gently. Differential diagnoses include odontogenic infection, chronic osteomyelitis, traumatic ulceration, fibro-osseous lesions and malignancy. Rapid progression, suspicious soft tissue or unexplained paraesthesia warrants reassessment. The eight-week definition must not delay treatment of spreading infection or investigation of cancer.

The Italian SIPMO–SICMF framework emphasizes clinical-radiological disease and non-exposed presentations. Its practical contribution is to distinguish the visible lesion from the complete pathological field: a small exposure may overlie extensive medullary disease, whereas sclerosis alone cannot establish MRONJ. Record the diagnostic framework used, particularly when comparing outcomes. Imaging-supported concern warrants specialist assessment before a patient necessarily fulfills an exposure-based research definition (Bedogni et al., 2024).

Imaging and laboratory assessment

Imaging should answer a specific clinical question. Periapical and panoramic radiographs evaluate odontogenic sources and provide an initial survey. Cone-beam CT delineates sequestra, cortical disruption and the relationship to the inferior alveolar canal; conventional CT is valuable when wider anatomical coverage, sinus disease or soft-tissue assessment is needed. MRI may clarify marrow and soft-tissue changes, but inflammatory signal does not directly define a necrotic margin. Nuclear imaging can show metabolically active disease beyond visible exposure, although specificity is limited. The 2025 MASCC/ISOO statement supports individualized modality selection and laboratory assessment directed by

comorbidity, particularly immune status and bleeding risk (Yarom et al., 2025).

CT review should distinguish osteolysis, sequestrum separation, periosteal reaction and mixed osteosclerosis. In 784 patients, these features were associated with different outcomes: sequestrum separation was favorable, while several diffuse or reactive patterns were less favorable. Absence of osteolysis does not exclude significant disease, particularly with denosumab. Imaging informs three-dimensional planning but does not provide a validated prescription for fixed resection margins (Otsuru et al., 2025).

Serum C-terminal telopeptide (CTX) is not a reliable surgical clearance test. A diagnostic-accuracy meta-analysis found inadequate performance at the proposed 150 pg/mL threshold. CTX should not be used to declare extraction safe, deny necessary treatment or prescribe an arbitrary holiday. Laboratory assessment instead addresses actionable problems including anemia, renal impairment, hyperglycemia, hypocalcemia, thrombocytopenia and neutropenia (Traboulsi-Garet et al., 2022).

A 2026 prospective cohort associated lower CTX and more extractions with MRONJ in denosumab-treated osteoporosis patients. However, nine events among 314 participants do not establish an externally validated decision threshold. A continuous association is different from sufficient individual predictive performance; CTX-guided procedural authorization remains premature (Yu et al., 2026).

Prevention before and during systemic treatment

Dental optimization should identify active infection, teeth with a poor prognosis and sources of repeated mucosal trauma. A tooth-level study in high-dose antiresorptive recipients linked apical lesions, periapical osteosclerosis and local infection to subsequent MRONJ. The clinical task is not indiscriminate extraction: restorable

teeth with controllable infection merit preservation, whereas a nonrestorable tooth with recurrent infection should not be retained simply to avoid surgery. When medical urgency permits, complete necessary invasive treatment and confirm satisfactory healing before high-dose therapy begins (Otsuru et al., 2024).

Prevention continues after baseline dental assessment. In high-dose zoledronic acid recipients, a 2026 retrospective comparison found MRONJ in 2.3% receiving structured maintenance versus 13.9% receiving a standalone pretreatment intervention. Nonrandom allocation limits causal inference, but the findings support ongoing periodontal care. Individualize recall to oral disease, exposure and self-care capacity; denture fit, caries and peri-implant inflammation remain relevant after dental clearance (Mauceri et al., 2026).

Avoiding every extraction may leave the biological driver untreated. Observational tooth-level data suggest that removing infected teeth can reduce subsequent MRONJ in selected oncology patients compared with retention. This does not justify indiscriminate extraction. Compare predictable endodontic or periodontal control with recurrent infection, anticipated medication exposure and extraction feasibility; explain that both persistent infection and intervention carry risk (Nakamura et al., 2024).

For indicated extraction, minimize trauma and periosteal stripping, smooth sharp unsupported bone, irrigate and obtain stable coverage without excessive tension. A cohort using alveoplasty and primary closure reported no MRONJ in 46 higher-risk patients; its uncontrolled design does not prove zero risk. Select prophylaxis according to exposure, immune status and local policy; prolonged antibiotics cannot compensate for inadequate source control (Arya et al., 2024).

Implant-related MRONJ may develop around previously integrated fixtures or after placement. Maintain peri-implant health; no dependable cumulative-dose threshold defines safety. High-dose oncology therapy generally argues against elective placement, whereas low-dose therapy requires individualized consent. A functioning, disease-free implant need not be removed solely because antiresorptive therapy begins (Andersen et al., 2025).

Drug interruption and denosumab timing

Prophylactic and therapeutic drug interruptions address different problems. The 2025 Korean multidisciplinary statement proposes selected bisphosphonate pauses and surgery approximately three to four months after denosumab injection. It also favors earlier active surgery and permits diagnosis before eight weeks when necrosis is otherwise established. These are attributable consensus recommendations, not proof that every interruption improves healing; application requires prescriber agreement and assessment of skeletal risk (Kim et al., 2025).

The 2026 Asia-Pacific consensus finds insufficient evidence that prophylactic discontinuation is beneficial. For osteoporosis-dose denosumab, it describes treatment approximately three to four months after administration, allowing healing within the dosing interval. This is planned timing, not an indefinite holiday. Recommendations for osteoporosis cannot automatically be transferred to monthly oncology regimens, where exposure and the consequences of withholding therapy differ (Taguchi et al., 2026).

A 2026 osteoporosis cohort observed intervention-associated MRONJ within three months of denosumab injection; longer intervals were associated with lower risk. This supports avoiding early elective surgery when feasible but establishes neither a universally safe month nor a reason to delay abscess drainage.

Document the last dose, procedure, review date and intended next-dose decision in a shared plan (Masri et al., 2026).

Denosumab cessation may provoke rebound turnover and multiple vertebral fractures. ECTS recommends an alternative antiresorptive strategy when treatment is discontinued, generally around six months after the final injection. Prolonged cessation should not be prescribed independently by the surgeon. If healing remains incomplete near the next dose, reassess competing risks jointly; delay, substitution and permanent discontinuation require distinct plans and follow-up (Tsourdi et al., 2021).

In cancer-associated MRONJ, a 2026 retrospective study associated withdrawal followed by surgery after sequestration with better healing. Differences in selection and operative timing preclude attributing benefit to withdrawal alone or assuming skeletal safety. Waiting may suit stable lesions, but infection, fracture risk or deteriorating function should not remain untreated to complete a predetermined holiday (Hata et al., 2026).

Nonoperative care and selection for surgery

Nonoperative care controls pain, infection and traumatic contact and supports patients for whom surgery is disproportionate or temporarily unsuitable. Provide cleansing, an appropriate antiseptic regimen, analgesia and antibiotics for clinically significant infection. Repeated antibiotics without reassessing the sequestrum or odontogenic source may suppress symptoms while disease persists. Specify the therapeutic goal and the findings that trigger escalation.

Discuss surgery for persistent or recurrent symptoms, uncontrolled exposure, radiological progression or functional decline. A prospective cohort associated operative care with disease resolution and improved quality of life, although selection bias and wide confidence intervals limit effect estimates. Surgery may

precede advanced complications when expected healing and functional benefit justify morbidity (El-Rabbany et al., 2022).

Early asymptomatic disease requires shared selection. A prospective stage 1 study found improved oral health-related quality of life with both approaches, without significant between-group differences in that outcome. Stable, small lesions in frail patients may be observed with reliable surveillance. A defined sequestrum or recurrent exposure in a fit patient may favor limited surgery (Rückschloß et al., 2023).

Before surgery, assess nutrition, anemia, renal function, glycemic and calcium status, antithrombotic therapy and oncological treatment timing. Confirm anesthetic fitness, wound-care capacity and follow-up access. Explain foreseeable extension of resection, sensory or tooth loss and reconstructive needs. Submit operative tissue for histopathology, especially when the diagnosis is uncertain or malignancy remains possible.

Principles of osseous surgery

The operative objective is removal of clinically significant necrotic and infected bone with durable coverage, while preserving useful anatomy when this does not compromise disease control. Sequestrectomy is appropriate for a separated, accessible sequestrum; debridement or marginal resection may suffice for more extensive localized disease. In a mandibular series of 206 patients, residual osteolysis, periosteal reaction and mixed osteosclerosis were associated with recurrence. The surgeon should therefore examine the entire imaging-defined field rather than merely smoothing the exposed surface. Nevertheless, sclerosis is not automatically equivalent to dead bone, and the evidence does not define a universal millimeter margin (Suyama et al., 2024).

Marginal resection preserves mandibular continuity only when the remaining basal bone is structurally and biologically

adequate. Segmental resection becomes appropriate when disease involves the inferior border, a pathological fracture is present, a reliable residual segment cannot be maintained, or limited treatment has failed in a diffuse lesion. A 2026 CT-based cohort associated certain radiological patterns with poor healing after marginal surgery; higher healing after segmental resection remained subject to confounding by indication. Resection should thus be individualized to disease distribution and reconstructive feasibility, not selected from a stage label alone (Kojima et al., 2026).

Assess the operative bed using imaging, bone appearance, sequestral boundaries and residual tissue quality. Bleeding alone is not a viability assay. Fluorescence may assist margin assessment; a randomized feasibility study found comparable outcomes with autofluorescence and tetracycline-assisted fluorescence, without establishing universal superiority over conventional surgery. It supplements anatomical judgment and cannot correct inadequate access or incomplete disease removal (Ristow et al., 2017).

Obtain deep microbiology samples when results can change treatment. Infectious-disease consultation is useful for recurrent or resistant infection, major immunosuppression and complex interactions. A retrospective cohort found no overall surgical advantage from routine consultation, supporting selective involvement. Revisit antibiotic choice and duration when microbiology, renal function or the clinical course changes (Nadella et al., 2025).

Soft-tissue closure and maxillary disease

Closure must be planned before bone removal. Preserve vascularized tissue, release tension judiciously, eliminate sharp edges and avoid a suture line directly over poorly supported bone where possible. A small mucoperiosteal flap may be sufficient for a limited defect, whereas extensive or previously operated wounds

may require additional vascularized tissue. In a retrospective malignant-disease cohort, submental island flap closure was associated with better outcomes than conventional mucoperiosteal closure. This supports considering regional tissue when local coverage is inadequate, while accounting for donor morbidity, neck anatomy and oncological suitability (Huang et al., 2024).

Maxillary MRONJ requires simultaneous attention to necrotic bone, sinus disease and separation of the oral and sinonasal cavities. Assess whether there is a true communication, retained sequestrum or impaired sinus drainage; involve rhinology when the extent of disease warrants it. A pedicled buccal fat pad is useful for posterior maxillary defects with suitable reach and volume. In a consecutive stage 3 series, 83.6% healed uneventfully after the initial procedure, and additional patients healed after reoperation. These results support its use in selected defects rather than treating it as a substitute for adequate osseous clearance (Andersen et al., 2023).

Segmental resection and reconstruction

Reconstruction should be designed around defect location, continuity, soft-tissue loss, expected survival and functional priorities. Vascularized bone offers living tissue and the possibility of later dental rehabilitation, but requires suitable recipient vessels, donor assessment and tolerance of a longer operation. In a multicenter series of 49 patients undergoing free-flap reconstruction for advanced MRONJ, flap survival was 96%; maxillary reconstructions had more debridement and intraoral exposure. Flap survival and eradication of MRONJ are separate outcomes, and a surviving flap does not eliminate the need to monitor the residual native jaws (Sweeny et al., 2024).

For mandibular continuity defects, a fibula flap can restore load-bearing bone, whereas a plate covered by vascularized soft tissue may reduce operative burden in selected patients. A small

2026 comparative cohort found better plate-related complication-free survival with fibula reconstruction; differences in overall wound complications and quality-of-life improvement were not statistically significant. Selection should incorporate vascular disease, mobility, donor-site consequences, prognosis and the likelihood of durable plate coverage. A shorter operation is not necessarily the least burdensome strategy if recurrent exposure subsequently requires repeated procedures (Lin et al., 2026).

Virtual planning and patient-specific fixation can assist restoration of mandibular form, but unexpected disease may require altered osteotomies or additional tissue. Implant rehabilitation requires stable healing and sustainable maintenance. For patients prioritizing rapid recovery, an obturator or removable prosthesis may provide greater practical benefit than a complex reconstructive pathway.

Adjunctive treatment and limits of evidence

Adjuncts require comparison with equivalent-quality standard care. Cochrane found low or very low certainty in the randomized evidence available through its search period. Hyperbaric oxygen, ozone, biological products and light-based approaches should not displace infection control or indicated surgery. Evaluate newer trials by durable healing, recurrence and adverse effects, not early symptom improvement alone (Beth-Tasdogan et al., 2022).

A 2025 randomized trial found no significant additional benefit from leukocyte- and platelet-rich fibrin. Among six-month evaluable patients, resolution was 92% versus 83% with surgery alone, with wide uncertainty and substantial attrition. Autologous concentrates may be feasible adjuncts, but cannot be presented as necessary for healing or as compensation for incomplete resection (Ramos et al., 2025).

A 2026 randomized trial reported better mucosal healing and fewer complications with adjunctive Er:YAG treatment in stage 2–3 disease, at the cost of longer surgery. Follow-up reached 24 weeks. This supports further evaluation of that specific protocol, not extrapolation to all lasers or photobiomodulation regimens; reproducibility and longer-term recurrence remain unresolved (Michalak et al., 2026).

Teriparatide may support repair in selected osteoporosis patients. A placebo-controlled trial involving 34 participants found improved lesion-level resolution and reduced bony defects after eight weeks added to standard care. Small numbers and lesion-level endpoints temper expectations. Metabolic-bone specialist assessment is essential; skeletal malignancy and bone metastases preclude routine use in the typical oncology-associated MRONJ population (Sim et al., 2020).

A randomized study reported improved outcomes with perioperative pentoxifylline and tocopherol in women with stage 1 osteoporosis-associated MRONJ. The selected population, large effect and subsequent control-group crossover limit extrapolation. Independent replication is needed before application to advanced oncology-associated disease. Review bleeding risk, interactions and tolerability; pharmacological adjuncts remain subordinate to adequate anatomical treatment (Colapinto et al., 2023).

Follow-up, recurrence and functional recovery

Review wound integrity, infection, pain, sensation, intake and function beyond initial mucosal closure. Image persistent symptoms or suspected recurrence. Distinguish persistence, recurrence after healing and a new distant lesion. A large 2026 cohort associated recurrence with bilateral and ramus involvement, although some estimates were imprecise. Extensive disease warrants

closer surveillance rather than automatic escalation of every operation (Park et al., 2026).

In a 2026 multicenter cohort of 1,007 patients, CT-derived lesion volume independently predicted recurrence, while an independent surgical-approach effect was not established. Baseline burden therefore matters when comparing outcomes. Volumetry remains dependent on segmentation and validation; it complements assessment without supplying an established numerical resection threshold (Ryu et al., 2026).

Assess recovery through eating, speech, hygiene and social participation. Prospective SF-12 and OHIP-14 assessment demonstrated improvement after surgery, supporting patient-reported endpoints. Address nutrition, prosthetic trauma and sensory symptoms while coordinating systemic treatment. Mucosal healing may coexist with disability; conversely, controlled symptoms and acceptable function may be meaningful success for a frail patient with residual disease (Hoene et al., 2024).

Conclusion

Effective MRONJ care combines prevention, anatomically informed diagnosis and timely treatment matched to the patient's systemic condition. Control of oral infection and continuing maintenance remain central throughout antiresorptive exposure. Decisions about drug interruption require shared responsibility, particularly with denosumab. Surgery should remove clinically relevant disease and secure reliable coverage while preserving function whenever feasible; advanced defects may justify vascularized reconstruction. The strongest clinical approach integrates current guidance with the limitations of the evidence, defines meaningful treatment goals and continues surveillance after apparent healing.

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CHAPTER 4

DENTAL IMPLANTOLOGY IN OLDER ADULTS: SYSTEMIC, ANATOMICAL, AND BIOMECHANICAL EVALUATION CRITERIA

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Giriş

1. A general overview: complex needs and treatment modeling

Dental implant treatment in the elderly population is not merely the mechanical replacement of missing teeth; it is a holistic rehabilitation process that directly affects the patient's mastication, phonation, nutrition, and psychosocial well-being. The physiological, cognitive, and systemic changes occurring in the aging individual necessitate the modification of standard treatment protocols.

The multidisciplinary evaluation model designed for older patients with complex treatment needs serves as a clinical guideline (1). This model is based on four main pillars when planning the patient's treatment:

1. Systemic and Medical Status: Risks associated with comorbidities and polypharmacy.
2. Cognitive and Psychiatric Capacity: The patient's cooperation with the treatment and ability to maintain long-term oral hygiene.

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3. Local Anatomical Factors: Three-dimensional morphology and the resorption pattern of the jawbones.
4. Prosthetic Expectations and Maintenance: The capacity of the patient (and the caregiver, if applicable) to maintain the prosthesis.

In the clinical decision-making process, the "biological frailty" level is more decisive than the patient's chronological age. When conducting the risk-benefit analysis of the treatment, the clinician must proportion the extent of the surgical trauma to the patient's healing reserves.

2. Bone morphology, vascularization, and biomechanical changes

The aging process leads to a decrease in bone mineral density, thinning of cortical layers, and widening of medullary spaces in the maxillofacial region, just as it does throughout the skeletal system. One of the most critical changes in geriatric jawbones occurs at the vascular level.

Ultrasonographic measurements have shown that mandibular arterial blood flow is significantly reduced in older patients (2). This decreased perfusion (ischemia) is a primary factor in the pathogenesis of alveolar ridge atrophy and age-related tooth loss. When an implant is placed in an ischemic and atrophic bone, the healing cascade at the bone-implant interface proceeds much slower compared to younger individuals.

The biomechanical response of bone tissue to implant loading also changes with age. Studies conducted on edentulous human skulls have investigated the transmission of bone strain in craniofacial bones during dental implant loading (3). Because the atrophic bone structure loses its capacity to absorb occlusal forces, stress concentrates directly on the cortical bone margins, which has been shown to increase the risk of peri-implant marginal bone loss.

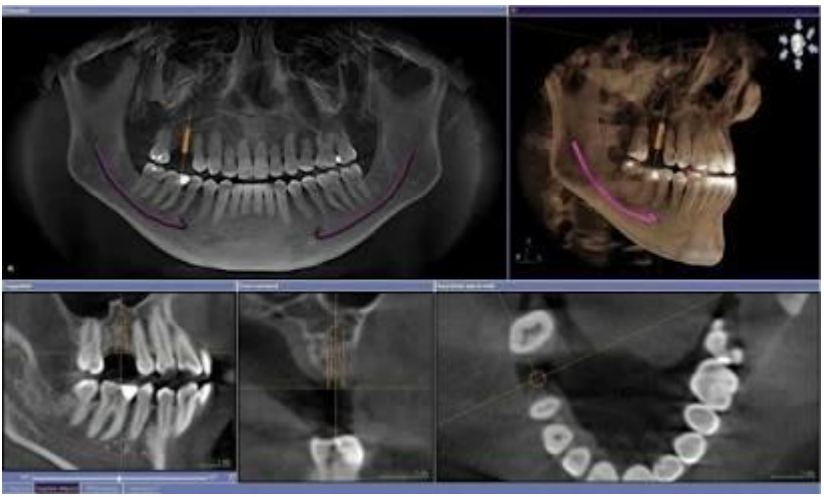


Figure 1: *Three-dimensional CBCT analysis in geriatric patients. Millimetric mapping of age-related bone atrophy (resorption) and critical anatomical structures such as the inferior alveolar nerve prior to implantation is essential to prevent iatrogenic nerve damage.*

3. Histological Changes and Dynamics of Wound Healing

Wound healing and osseointegration in geriatric patients are directly under the influence of cellular aging (senescence). How aging disrupts the wound healing cascade has been explained at the cellular level; it has been reported that the hemostasis, inflammation, proliferation, and remodeling phases are all delayed with age (4, 5).

3.1. Inflammatory response and mucosal healing

It has been shown that the inflammatory response to dermal and mucosal injuries is altered with age; specifically, neutrophil and macrophage infiltration slows down, which increases susceptibility to infection (7). It has been clinically proven that not only age but also sex plays a role in mucosal wound healing; specifically, decreased estrogen levels in postmenopausal women dramatically reduce the rate of oral mucosal healing (6).

3.2. Bone Healing at the Molecular Level

Delving into the molecular foundations of bone healing reveals the critical role of the Cyclooxygenase-2 (COX-2) enzyme. In studies conducted on aged mouse models, it was found that COX-2 expression significantly decreases with aging (8). COX-2 deficiency slows the differentiation of mesenchymal stem cells into osteoblasts and suppresses endochondral ossification. This situation explains at the molecular level why fracture repair and peri-implant bone formation are significantly delayed in aged bone. The reflection of these specific aging data obtained from the literature on surgical protocols is summarized in the table below:

Table 1: *Age-Related Physiological/Anatomical Changes and Surgical Modifications in the Geriatric Population*

Parameter	**Age-Related Physiological/Molecular Change**	**Impact on Implant Surgery**	**Geriatric Modification Strategy**
Vascularization (Blood Flow)	Reduced mandibular arterial blood flow and ischemic tissue profile (2).	Delay in the osseointegration cascade and bone formation.	Prolonging the healing (waiting) period, avoiding early loading.
Molecular Level (COX-2)	Significant decrease in COX-2 expression in aging bone (8).	Slowing down of the differentiation of mesenchymal stem cells into osteoblasts.	Keeping surgical trauma to a minimum, utilizing low-speed drilling

Parameter	Age-Related Physiological/Molecular Change	Impact on Implant Surgery	Geriatric Modification Strategy
			(low heat generation).
Mucosa and Inflammatory Response	Prolonged inflammation phase and thinning oral mucosa due to decreased estrogen (postmenopausal) (4, 6, 7).	Increased risk of soft tissue dehiscence, infection, and postoperative morbidity.	Employing flapless computer-aided guided surgery in eligible cases.
Surgical Duration	Decreased tolerance of aging tissues to surgical stress (10, 11).	Exponential increase in postoperative pain, edema, and trismus as duration increases.	Simplifying surgery by selecting short/narrow implants instead of major bone augmentations.

4. General systemic condition and relationship with surgical duration

In dental practice, older patients frequently present to the clinic with multiple chronic diseases and polypharmacy tailored to these conditions. Cardiovascular diseases, diabetes, anticoagulant use, and medications affecting bone metabolism are primary risk factors that the clinician must manage prior to implant surgery (9).

However, another important parameter that should not be overlooked in geriatric patients is the duration of the operation. Studies based on impacted lower third molar surgeries have shown that the patient's age and surgical duration exert a combined effect on postoperative inflammatory tissue reactions (pain, edema, trismus) (10, 11). As the surgical duration increases, postoperative morbidity increases exponentially. This data proves how vital it is to keep the surgical duration as short as possible in geriatric implantology.

5. Mandibular surgical assessment and complication management

The mandible, especially when edentulous, harbors specific and potentially life-threatening risks in implant surgery due to its atrophy pattern. A large-scale survey conducted in the Netherlands on atrophic edentulous mandibles highlighted that iatrogenic mandibular fractures associated with implant surgery, although rare, are a geriatric complication leading to severe morbidity (12).

5.1. Anterior Mandible: Hemorrhage and Airway Obstruction

Although the anterior mandible is considered a safe surgical site, perforation of the lingual cortical plate can result in disaster in cases of severe atrophy. Cases of sublingual hematoma developing rapidly as a result of damage to the sublingual or submental branches of the lingual artery during anterior mandibular implant placement are widely covered in the literature (13, 14, 15).

These excessive bleeding events in the floor of the mouth can push the base of the tongue upward and backward, obstructing the airway; it has been reported that these cases can reach fatal proportions requiring emergency tracheostomy (16, 17). Therefore, the presence of lingual undercuts must be carefully evaluated on CBCT in geriatric patients.

5.2. Posterior Mandible: Neurological Risks

In the posterior mandible, the inferior alveolar nerve and mental foramen region are the primary constraints. Examinations using CBCT have proven that accessory mental foramen variations are seen more frequently than traditionally thought (18). The management of iatrogenic trigeminal nerve injuries is quite challenging (19). It has been reported that even if nerve repair (microsurgery) is performed, the patients' sensory satisfaction and gratification levels remain low postoperatively (20).



Figure 2: *The instrument kit used in osteotome-mediated (closed) sinus floor elevation, which is less traumatic for geriatric patients. It should not be forgotten that the mechanical shock created by the mallet during the procedure can, albeit rarely, lead to Benign Paroxysmal Positional Vertigo (BPPV) in older patients (24, 25).*

6. Maxilla: Sinus pneumatization and osteotome applications

The posterior region of the maxilla is characterized by the downward sagging (pneumatization) of the maxillary sinus following tooth loss. In cases where bone height is borderline, osteotome-mediated closed sinus floor elevation applied through the crestal approach is a much less invasive option in geriatric patients to avoid the morbidity of massive lateral window (open sinus) operations (21). Bone

remodeling around implants placed with the osteotome technique and their long-term radiographic success have been clearly proven (22, 23).

6.1. Sinus Membrane Perforation and Grafting

The most common complication in sinus surgery is the perforation of the Schneiderian membrane (26). In more severe cases, displacement of the implants into the sinus cavity may occur, a condition that requires endoscopic surgical approaches (27, 28). When the histomorphometric healing of bone grafts (autograft, allograft, xenograft) placed in the sinus cavity is examined, meta-analyses have supported that different graft materials produce similar and predictable bone volumes (29, 30, 31).

7. Simplifying surgery: Biomechanics and implant dimensions

The morbidity carried by advanced surgical procedures such as autogenous block graft harvesting is high in geriatric patients (32). This situation has led clinicians to favor shorter and narrow-diameter implants. Three-dimensional finite element analyses performed in the maxilla have shown that the stress distribution at the implant-bone interface is directly related to the crest geometry (43, 44).

7.1. Scientific Foundations of Short and Narrow-Diameter Implants

When the effect of implant length and diameter on survival rates was investigated, it was proven that short implants have similar success rates to long implants when appropriate occlusal loading is applied (33). It has been biomechanically confirmed that stress is largely concentrated at the crestal neck of the implant and that the apical length of the implant is not effective in absorbing stress (34, 35). When the stress distribution of implants of different diameters was examined, it was found that an increase in diameter reduced the strain on the crestal bone more than an increase in length (36).

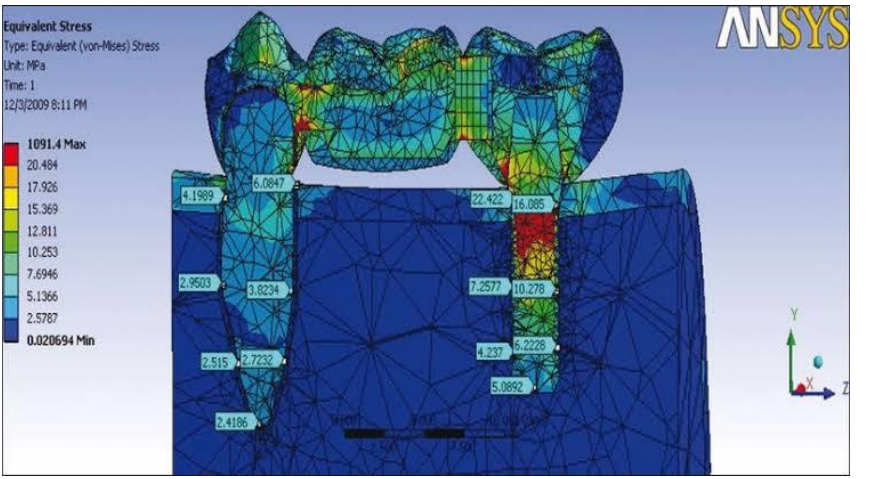


Figure 3: *Finite Element Analysis. Stress distribution of occlusal forces on the implant body and surrounding bone. Biomechanical studies have proven that stress concentrates mostly in the neck (crestal) region of the implant; therefore, subjecting geriatric patients to major grafting stress for the sake of using a longer implant is unnecessary (34, 35).*

Table 2: *Biomechanical Strategies and Avoidance of Major Grafting in Elderly Atrophic Crests*

Biomechanical Strategy	**Clinical Rationale for the Geriatric Population**	**Literature Basis**
Narrow-Diameter Ti-Zr Alloy Implants	To protect the patient from autogenous block graft morbidity (and a second surgical site like the hip/ramus) in crests thinned to a knife-edge due to senile atrophy.	Barter et al. (38), Chiapasco et al. (39)
Extra-Short (4 mm) Implants	To eliminate the risk of inferior alveolar nerve damage and avoid challenging nerve transposition surgeries in the	Slotte et al. (37)

Biomechanical Strategy	Clinical Rationale for the Geriatric Population	Literature Basis
	severely resorbed posterior mandible.	
Bicortical Anchorage	To compensate for the weakened primary stability in Type 4 (osteoporotic medullary) bone, which is frequently seen in older patients, by anchoring the implant apex to the sinus or nasal floor cortex (dense bone).	Pierrisnard et al. (34)
Zygomatic Implants	To provide strong posterior anchorage in a single session without grafting and long waiting periods in older individuals with an extremely atrophic maxilla.	Aparicio et al. (42)

8. Patient Satisfaction, Prosthetic Success, and Evidence-Based Literature

The ultimate goal of implant surgery is to restore the patient's quality of life with a prosthetic superstructure. It has been reported that the survival rates of fixed implant-supported restorations applied in the edentulous maxilla are high and successfully restore occlusal functions (45).

It has been revealed that the way the patient perceives the treatment cost and the psychological acceptance of the implant are directly linked to the satisfaction level achieved (46). Even in patients with recessive dystrophic epidermolysis bullosa, whose mucosa is

extremely fragile, implant-supported prostheses dramatically elevate the quality of life (47).

There is a bias that must be considered when translating literature data into clinical practice for geriatric patients. When patient recruitment processes for clinical trials are examined, it has been emphasized that patients included in the articles generally have "ideal" systemic conditions, and patients with uncontrolled diabetes or severe polypharmacy are usually excluded from these studies (48). Therefore, treatment success in geriatric implantology is possible by adapting evidence-based data to the individual vulnerabilities of the patient.

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