Complex Dental Implant Complications

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Foreword

Atul Gawande wrote a book, one of many: *The Checklist Manifesto: How to Get Things Right*

Why are books like this necessary? What creates a need to describe our foils in surgery?

In 1965 Per-Ingvar Branemark placed the first titanium implant in his patient Gosta Larrson at the University of Gothenburg. The purpose of this single surgical procedure was to treat complete mandibular edentulism in a debilitated patient. This single surgical procedure changed reconstructive medicine and dentistry forever. For the first time a metal cylinder could be used for the reconstruction of the missing dental units or teeth in a predictable outcome. Professor Branemark discovered the uniqueness of titanium as an elemental material that could be accepted by the human body and not elicit an immune response creating a new environment for the replacement of teeth and mechanical body parts. He described it as *Osseointegration*. This single discovery essentially changed the way dentistry and to some degree medicine would be practiced forever.

Originally, the training needed for the surgical and the prosthetic rehabilitation was limited to a select few and reserved in a careful fashion by Branemark and his co-workers in special seminars. However, the techniques became refined and replicated, and industry soon found that the science was sound and that the outcomes were predictable and long standing. Thus, there was an explosion of dental implant therapy throughout the world. Today, the use of implant surgery and reconstruction has become an accepted procedure. Many clinicians now use the principles of osseointegration as a standard for reconstruction of missing teeth and other body parts.

The reconstructive use of implants is now commonplace. All aspects of dentistry have come to depend on the strategies of this technology for reconstructive purposes. Originally, a carefully controlled process, it is now practiced by all facets of dentistry. Multiple disciplines within dentistry now provide care for their patients using their expertise to solve difficult problems. However, this is not without complications that involve all aspects of the reconstruction process. The question that is often asked is: why are there complications and more importantly how do you solve or prevent them? In essence why do they happen?

Many different reasons have been attributed to the continued increase in complications or untoward outcomes. There are the human factors, the issues of surgical stress, various risks and hazards of treatment, and most importantly the issues of

human error. Even the simple lack of adequate treatment planning can be at the root of many of these problems. Traditionally, when first introduced, the Oral and Maxillofacial Surgeon was looked to as the single person to be trained and to introduce this technology to other colleagues. There was in fact a time when Professor Branemark only trained the OMS in the surgical techniques within the treatment theater. Gradually, other surgical specialties and non-surgeons were introduced and trained in implant care. Their expertise led many to follow the original pathway and develop new treatments that helped many.

As it became clear that not every patient could sustain the implant surgery given their lack of an adequate bony platform, techniques were designed to increase the available bone and soft tissue so that more people could be treated. Professor Branemark realized early that many patients were too compromised to be acceptable for care and thus described various procedures to allow for more implants to be placed in the compromised sites. Soon the scope of who placed and restored these implants widened and more clinicians were placing and restoring the implant or fixtures as he described them. Various bone materials and bone substitutes were discovered for augmentation of the compromised patient. The strict techniques were "modernized" and even more doctors were involved in the placement process. Today, the use of the implant platforms for reconstruction is now practiced across the entire spectrum of clinical dentistry. This has resulted in an increase of untoward outcomes or complications as the spectrum of care has been advanced to encompass more patients. Many of the complications relate to a lack of a basic understanding of the biology of bone and the human species. The complications range from the simple implant failure to complicated losses of grafts, vital structures, and irreversible damage to soft and hard tissue. The oral and maxillofacial surgeon has become the major entity to resolve many of these difficult problems. This book, written by OMSs, delineates the issues of serious complications and ways to reach acceptable outcomes. The unique talent and expertise of these individuals (authors) help others understand the need for an appreciation of basic biology, wound healing, and the importance of adequate outcomes in a new world filled with commercialism and an emphasis on technology versus the human element of healing.

Following the topic outlined in this book and the vast descriptions of treatment scenarios will help each clinician solve or avoid timely mistakes; I urge each person to read and follow this detailed book to help avoid complications and realize a firm reproducible outcome for the patient whom we must all protect.

In closing I refer to a quote by Jean-Gagriel Charrier in the book ***The Search for the Weakest Link: An Introduction to Human Factors****:* "Human beings, with their beliefs, values and motivations, their commitment to their vocation and lastly, their behaviors are naturally integral to human factors" (1).

We must all remember our goal of protecting the patient through adequate training and knowledge and protect them from adverse outcomes. This book is paramount to that goal and our understanding of complex complications in Implant Dentistry. In summary, we must all remember our goal in patient care "Do No Harm."

Portland, OR, USA Jay P. Malmquist

Preface

Surgical interventions, regardless of complexity, has the potential for complications. The continued upsurge in the aging population has been accompanied with a great need for dental implant rehabilitation. The high predictability of implant treatment with this tremendous need has spurred the dental profession across specialties to incorporate this treatment into their practices regardless of training and/or overall experience. Clinicians acquiring the skills for dental implant surgery share comparable backgrounds commiserate with a doctoral degree in dentistry. Today, the majority of clinicians performing implant surgery have additional training in their respected specialties, such as oral and maxillofacial surgery, periodontology, prosthodontics, advanced general practice dentistry, as well as postdoctoral courses in implantology. The variety of paths has created clinicians with a broad range of training and competencies, especially as it relates to the recognition and management of major implant complications. The interactions between the mentioned professions have predominantly been complementary both in clinical practice and in the literature. The fundamental purpose and goal has been to advance the science and knowledge of dental implantology.

The vast majority of implant dentistry results in successful dental rehabilitation. However, the incidence of disastrous complications, although rare, has become more commonplace and is now being documented in the literature. Unfortunately, this surge of dental implant surgery has brought a new class of major surgical complications and disabilities.

The purpose of this text is to share with implantologist, irrespective of their background, the plethora of complications that can occur even in routine implant surgery. A detailed preoperative assessment, hopefully, can help the implantologist avoid poor outcomes and complications. However, the implantologist must continue to strive for ideal outcomes by continuing education, optimizing treatment plans, surgical techniques, knowledge of the anatomy and medicine, proper patient selection, and detailed maintenance. Despite all the above, complications can occur. Equally important is the early recognition and management. The potential to limit further morbidity may be dependent on early and interceptive diagnoses and surgical management. It is imperative to avoid exacerbation of a complication, such as under treatment or estimation of a local infection resulting in a more serious complication such as osteomyelitis or an early neuropraxia leading into a chronic pain syndrome. Failures to recognize, diagnose, and treat the initial problem can lead to

subsequent clinical, psychological, and medicolegal issues for patients and clinicians.

The goal of this text *Complex Dental Implant Complications* is to increase the implantologist's knowledge and awareness of the broad spectrum of complications, ranging from the initial workup to the actual placement and postoperative period. We outline the diagnosis and management of several categories of complications by some of the most expert surgeons in the field.

Oral and maxillofacial surgeons (OMFS) are at the apex of implantology, especially as it relates to the management of major morbidity associated with implant surgery. Although prosthetic complications are of equal importance, they are not addressed in this surgical text. It is clear that poor surgical treatment can compromise prosthetic rehabilitation and vice versa. The majority of the complex complications discussed in this text are best managed by experienced OMFS with surgical and medical capabilities that extend well beyond the dentoalveolar region. Examples of this include complications related to medical issues, anatomic factors (e.g., vascular injuries), pharmacologic factors (e.g., drug-induced osteonecrosis), nerve injuries (inferior alveolar or lingual nerves), and sinus-related complications or severe infectious complications, such as osteomyelitis requiring surgical and medical management.

We hope to improve patient care through knowledge, recognition, prevention, and when necessary surgical intervention.

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Mark R. Stevens and Kyle Frazier

1 Introduction

The phenomenon of osteointegration was first described by Bothe et al. in 1940 and later by Leventhal et al. in 1951 [1, 2]. When Brånemark, who first coined the term "osteointegration," placed his first dental implants into a human volunteer, the underlying major factor for implant placement was bone quality and quantity [3]. The evolution, application, and advancements of dental implant rehabilitation have grown exponentially.

The simultaneous development of unique prosthetics designs, customized components, guided tissue regeneration, in-office contemporary imaging, and computer software has greatly increased implant applications and restorative possibilities. Other major factors include the ever-increasing number of patients who could benefit from dental implants (i.e., baby boomers [4]), high predictable success rate [5], and the desire of dentists to bring this technique to their patients. Today implant surgery is a common practice and is a growing part undergraduate curriculum in dental schools [6].

Unfortunately, with the expansion and evolution of dental implant treatment in most dental practices, an increase in complications and morbidities associated with dental implants has occurred. The inherent high cost of implant dentistry in combination with patients' high expectations has inevitably brought its share of complications and legal malpractice claims [7]. A vast majority of these complications are directly attributed to poorly designed treatment plans and insufficient or in-accurate preoperative workup.

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The prevention of complications should start with a detailed comprehensive preoperative assessment. The preoperative assessment should require a comprehensive medical history, a thorough clinical and radiographic examination, and a planned prosthetic design.

The adage "prosthetics drive implant surgery" is an absolute truism. The initial goal in developing an appropriate treatment is mandated by the type and extent of the prosthetic restoration [8] (Fig. 1).

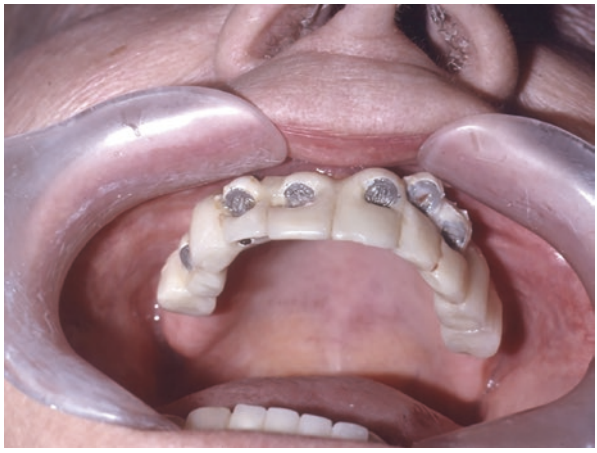
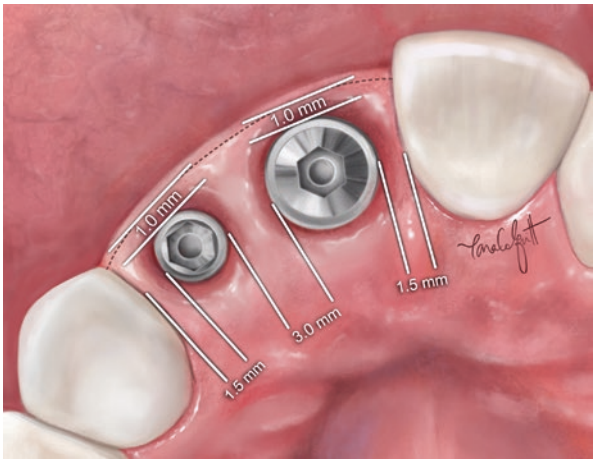


Fig. 1 Implant placement was performed without regard to the final prosthetic design, resulting in implant emergence through the facial surface of the prosthetics



2 Initial Consultation

The purpose of a thorough treatment plan is to formulate, organize, and document the patient's pretreatment conditions. A well-thought-out comprehensive treatment plan can prevent and avoid unrecognized surgical or prosthetic problems.

Two important questions must be answered prior to formulating a definitive implant rehabilitation and treatment plan:

1. What are the patient's desires and expectations?
2. How much does the patient want to invest in their implant rehabilitation?

Subsequently, the type of prosthesis planned will dictate the number, locations, and even the angulations of the dental implants. Additional cost (i.e., pre-implant site reconstruction, interim prosthesis, custom prosthetic abutments) and time of the treatment must also be thoroughly conveyed to the patient. Hygiene compliance and recall must also be included in the discussion. Recall may include fees for replacing attachments or removal of screw-retained prostheses and cleanings.

Difficult cases may require a multidisciplinary approach involving other dental specialties. The literature continues to correlate implant complications and failures to three major factors: the implant system, the patient's health/habits, and the dentist's experience level. More commonly, complications arise from an inadequate preoperative assessment and prosthetic setup prior to treatment.

The pre-surgical and prosthetic workup should include the following:

- A thorough health history.
- A detailed systematic functional and cosmetic orofacial examination.
- An appropriate radiographic exam, which may include:
  - Cone-beam computed tomography (CBCT) with virtual planning software.
  - A panoramic radiograph with determined magnification.
  - Periapical films with determined magnification.

Other aids to the pre-surgical and prosthetic workup may include:

- Study models, either traditional or digital.
- Computer software for digital implant and prosthetic planning.
- A detailed wax-up, when appropriate.
- Surgical guides.
- Preoperative photos, both extra-oral and intra-oral.

A systematic evaluation of both the facial dimensions, as well as a thorough oral cavity exam, is important in implant planning and prosthetic rehabilitation. A general facial analysis for asymmetry must be part of the overall preoperative assessment. General knowledge and collection of facial proportions, dental midline, and peri-oral soft tissue abnormalities of the lips are essential. This includes upper and lower lip line in repose and in animation [9]. The literature reports that the average incisor show in repose for men is 1.9 mm and in women 3.40 mm; however, there is

a wide range of gingival show at smile. Gingival show greater than 3 mm usually is regarded as excessive. The lower lip can identify orientation of the incisal plane and should contact the maxillary incisors on smile.

In dentate cases, it is critical to evaluate the condition of the existing teeth. This includes their periodontal and restorative condition, morphology, position, and reference to the incisal and occlusal planes. It is also important to identify the presence of cants, which are often seen in patients with facial asymmetries. The incisal plane should be parallel to the pupillary plane. Changes in the incisal plane can be due to numerous dental causes, such as attrition and/or poorly designed existing restorations. Posteriorly, premature loss of molars and premolars, excessive mesial drift, and collapse of the vertical dimension will affect the occlusal plane and peri-oral soft tissue support. Interceptive orthodontics and/or even orthognathic surgery may be necessary prior to implant placement. Figure 2 demonstrates a complex interdisciplinary approach to implant rehabilitation.

Unfortunately, many patients who sign informed consent documents and proposed treatment plans are not well informed about the overall plan or procedure they are consenting to. In a study of 100 patients admitted for elective surgical procedures and given procedure-specific brochures, investigators report that 38% of patients could not correctly describe the nature of the surgery/procedure, and 54% could not name at least one potential complication [10]. Documentation of counseling the patient about the possibility of long treatment times will minimize risk to the practitioner.

In addition, it is imperative to develop good patient–doctor rapport during the evaluation. This will enhance case outcomes, especially in multiphasic and complex implant treatment plans [11].

3 Medical History

Every preoperative implant evaluation and treatment plan should begin with a thorough medical and dental history including the patient's emotional and psychologic health. The medical history helps to assess whether the patient has the physical and psychologic health to undergo implant surgery, both during the surgical phase and the subsequent long and trying prosthetic rehabilitation phase [12].

There are numerous systemic medical conditions, drugs, and patient behaviors that contraindicate or significantly decrease the predictability of dental implants. Those factors, in combination with implant surgery, can result in serious complications and residual morbidities [13]. A detailed discussion of risks and compromised outcomes must be presented to the patient. The effects of medical comorbidities in the outcomes of patients undergoing implant surgery will be discussed in a subsequent chapter.

4 Soft Tissue Evaluation

The periodontal soft tissue is one of the most important aspects when performing implant surgery. This is especially true in the esthetic zone. Soft tissue health and biotype should be accurately noted in the preoperative soft tissue assessment.

Fig. 2 (**a**–**g**) Complex interdisciplinary treatment. (**a**) preoperative view showing poorly designed prosthesis and decreased intra-arch space (**b**) mock setup of maxillary teeth and needed change in vertical dimension in relation to lip line (**c**) diagnostic wax-up, arch width and vertical discrepancy, extraction of mandibular incisor and intrusion of remaining mandibular incisors with orthodontic treatment (**d**) CBCT and surgical placement of implants (**e**) photo demonstrating pre-op/post-op dental changes (**f**) photo demonstrating pre-op/post-op facial cosmetic changes (Courtesy Dr. Jamie Londono (prosthodontist) and Dr. Eladio DeLeon (orthodontist))

Olsson and Lindhe [14] have listed two distinct biotypes, "thin and scalloped" and "thick and flat." These biotypes respond differently to surgical manipulation and prosthetic restorations. The thin scalloped form is predisposed to recession and loss of attachment. The biologic seal and attachment are also weaker and more delicate than the normal tooth-gingival attachment [15]. Hence, repeated trauma and/or mild inflammation may initiate osteoclastic activity in the underlying hard tissue leading to bone resorption [16]. Traumatic second-stage surgery or provisional restorations can also accentuate damage. Thus, soft tissue manipulation should be minimized in the patient with thin biotype. For example, flapless, papilla sparing, or "U" shaped approaches can help preserve these types of soft tissues. Patients with the thick and flat gingival tissue biotype will have greater resistance to dehiscence and recession, but are predisposed to scarring, pressure resorption of grafts, and notching [17].

Vascularity around implants is less than around natural teeth. Thus, these sites are subject to slower healing. In addition, periodontal pocketing around healthy implants is generally deeper than around healthy teeth. The average biologic width around an implant is 3–4 mm, slightly longer than a natural tooth [18].

Peri-implant soft tissues should have appropriate contours and create a self-cleansing environment, minimizing food accumulation. This leads to a healthy, predictable implant, as it prevents marginal inflammatory lesions that can affect the gingival attachment and lead to subsequent bone loss. In addition, Tarnow et al. showed that maintaining a distance of 5 mm between the interproximal contact points and the interproximal bone crest will avoid loss of the papilla and the inevitable resulting "black triangle." [19]

5 Hard Tissue Evaluation

The chief method of hard tissue evaluation is via radiography. Conventional two-dimensional radiographs, such as periapical and/or panoramic, allow screening for pathology and provide measurements of distance to adjacent structures, such as roots, sinuses, and nerves. However, they fail to provide cross-sectional dimensions important in planning implant widths and thus total integration surface [20, 21]. The magnification of panoramic radiographs can be >30%, and vertical measurements can be unreliable because of foreshortening and/or elongation of anatomic structures due to misalignment of X-ray beams. Magnification distortions can be corrected by using markers with known measurements, like ball bearings. These standardized measurements are then used to calibrate the rest of the image.

In contrast to the limitations of conventional radiography, the ideal imaging technique for dental implant surgery should have the ability to visualize the implant site in three dimensions. It should provide an accurate measurement of the mesio-distal, bucco-lingual, and superior-inferior dimensions. Computerized tomography (CT) provides this information. Due to the high amount of radiation exposure, prohibitive cost, and limited patient access to conventional CT imaging, the cone-beam CT (CBCT) was developed and is now widely implemented in oral & maxillofacial and

dental practices throughout the world. Although the CBCT provides greater anatomic information than conventional dental radiographs, it does not increase the ionized radiation risk to the patient [20]. Furthermore, in a comparison of conventional CT scans to CBCT scans, the CBCT was found to be more accurate when assessing bone [22–25].

CBCT scans also allow the implantologist to evaluate trabecular bone density and cortical thickness. Classification of bone density types was first presented by Lekholm and Zarb in 1985 [26]. This information is critical in osteotomy preparation. The density within the units is a fairly accurate assessment of the bone quality, (D1 bone, >1250 HU; D2 bone, 750–1250 HU; D3 bone, 375–750 HU; D4 bone, <375 HU) [11]. Access to this data alerts the implantologist to the possible need to under-prepare, condense, or pre-thread (tap) the osteotomy to achieve maximum stability.

When considering full arch prosthetic reconstruction, certain areas in the alveolar arches are considered more ideal. Careful radiographic review of these strategic positions includes the regions of the central incisors, canines, first premolars, and first molars. In the anterior maxillary and mandibular arches, there are often normal anatomic recesses apically. These areas may require preoperative grafting to allow for ideal implant placement and angulation. Other sites deficient in bone width or height may require guided bone regeneration procedures prior to implant surgery. In contrast, some sites may require bone removal prior to implant placement. This is common when needing to increase interocclusal space or when flattening the alveolar ridge is necessary to increase width at the alveolar crest.

6 Clinical Alveolar Ridge Assessment

Bone resorption after tooth loss often results in three-dimensional deformities. These alveolar ridge defects are usually a combination of both bone and soft tissue deficits. There are multiple classification systems of alveolar ridge defects. Examples include those based on volume, presence of anatomic walls, and associated soft tissue deficiency [26, 27]. A clinical assessment should include a thorough visual inspection, palpation, and radiographic analysis. Bone sounding with a needle or bone calipers can be used to map out the defect and measure soft tissue thickness. Radiographic templates in combination with computerized tomography software demonstrating the prosthetic overlay are extremely helpful in assessing the defect. Models and mounted diagnostic casts with a planned prosthetic waxed-up over the defect provide a three-dimensional assessment of the volume and soft tissue deficiencies.

It is also important to evaluate the periodontal support of the adjacent teeth since they may be compromised and part of the bony deformity. Preoperative planning of large alveolar ridge defects with vertical bone loss will almost always require staged reconstruction. Since large bony defects will require mobilization of the overlying soft tissue, the health, biotype, and amount of mucosa should be documented. These types of reconstruction can be unpredictable and may require multiple secondary procedures (Fig. 3).

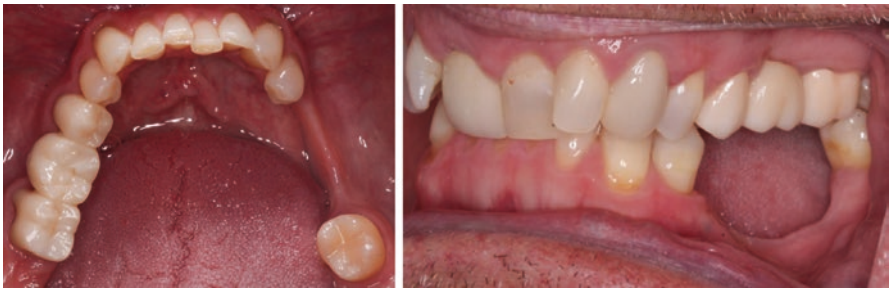


Fig. 3 Severe alveolar ridge height and width deficiency likely to require multiple bone grafting procedures prior to implant placement

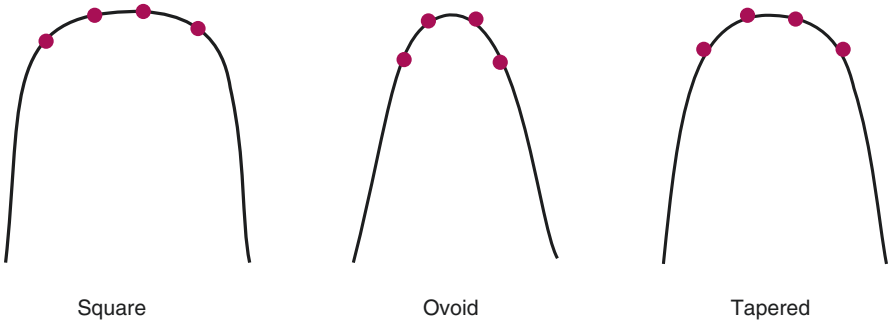


Fig. 4 Differences in arch shape can influence A-P spread and the allowed cantilever distance of fixed dentures

7 Dental Arch Assessment

The shape of the arch form is key to implant positioning for edentulous cases. Anterior-posterior (A-P) spread is defined as "the distance from the center of the most anterior implant to a line joining the distal aspect of the two most distal implants on each side" [28]. The A-P spread determines how far a fixed denture may be cantilevered off the distal implants. In situations in which anterior and posterior implants are placed close together, the restoring dentist will be constrained to providing a short denture that may not include molars. Thus, increasing the A-P spread is paramount to the success of edentulous cases. Square arch forms can decrease the ability to provide proper A-P spread, thereby decreasing the cantilever length compared to an ovoid or tapered arch form (Fig. 4).

In addition to the evaluation of single arches, examination of how the maxillary and mandibular arches relate to one another is essential. One major area of concern which surgeons tend to overlook is interocclusal space. A successfully integrated implant which has ideal angulation but lacks sufficient overlying interarch space for prosthetic rehabilitation is, unfortunately, a failure. This is true in both dentate and edentulous cases. Although edentulous cases give the perception that there is ample room for prosthetics, the practitioner must remember that the patient has an ideal vertical dimension

of occlusion. If implants are placed without regard to this measurement, the restoring provider may need to adjust the prosthetic plan to compensate, either by opening the vertical dimension of occlusion or by decreasing the prosthetic thickness. If the mandible is opened excessively to allow for an ideal thickness of prosthetic material, this may result in chronic discomfort or lip incompetence. If material thickness is reduced, prosthetic fracture may occur [29]. Thus, in all implant cases, the desired prosthetic material (e.g., porcelain, acrylic, zirconia), prosthetic design (e.g., screw-retained vs. cement-retained, overdenture vs. fixed denture), and vertical dimension of occlusion should be determined in the implant planning phase. If these variables are chosen after implant placement, it may be found that there is, in fact, no proper way to restore the case. In addition, when treatment planning fixed dentures, careful evaluation of ridge height and lip length at rest and upon animation should be performed to ensure there will not be an unsightly show of the ridge-prosthetic junction. If so, additional bone reduction may be considered for purely esthetic reasons, when appropriate.

8 Ideal Implant Positioning

Ideal implant positioning factors in all the aforementioned data obtained in the hard tissue, soft tissue, alveolar ridge, and dental arch evaluations. For instance, the width of alveolar bone may influence the bucco-lingual position chosen for the implant, or it may necessitate a grafting procedure be performed prior to implant placement. Thus, the selection of the implant position is the culmination of a good preoperative evaluation. In addition, there are standard guidelines for spacing of implants, listed in Boxes 1 and 2 below. Failure to follow these guidelines will result in complications as outlined in the implant complication table at the end of this chapter (Table 1).

Box 1

Recommended spacing for implants
Implant to tooth—1.5–2 mm
Implant to implant (fixed restorations)—3.0 mm
Implant to buccal/lingual plates—1.0 mm
Implant to maxillary sinus/nasal cavity—1.0 mm
Implant to inferior alveolar canal—2.0 mm from superior aspect of canal
Implant to mental nerve—5.0 mm from anterior extent of mental foramen
Implant to inferior border of the mandible—1.0 mm

Box 2

Recommended minimum distances for overdenture and hybrid restorations
Implant to implant (overdenture) 5.0 mm
Implant to incisal edge (overdenture) 9–11 mm
Implant to implant (hybrid) >1.5 mm
Implant to incisal edge (hybrid) 15–18 mm

Table 1 Root-cause assessment in implant complications

Complications	Root cause
Soft tissue assessment	
1. Chronic gingival collar inflammation	1. Reduced or missing attached gingiva
2. Loss of gingival collar around implant	2. High frenum or muscle attachments at implant site
3. Long gingival collar/peri-implantitis	3. Thick mucosa at the implant site
4. Chronic gingival inflammation dehiscence	4. Thin mucosa at implant site
Hard tissue assessment	
1. Fenestration of cortical plate	1. Inadequate bucco-lingual width
2. Sinus perforation	2. Pneumatized maxillary sinus
3. Nerve injury	3. Superior position of the IAN
4. Compromised implant position	4. Acquired bony defect/inadequate bone space
Dental arch assessment	
1. Contraindication for implant placement	1. Insufficient interocclusal space
2. Adjacent tooth injury/bone loss/compromised prosthetics	2. Insufficient mesial distal space
3. Occlusal force overload/progressive (bone loss) disintegration	3. Para-functional habits progressive (bone loss) disintegration
4. Poor implant angulation	4. Malposition of teeth adjacent to the edentulous space
5. Short prosthesis/decreased masticatory surface area	5. Wide arch form/decreased AP spread
Interarch assessment	
1. Prosthetic fracture	1. Inadequate prosthetic volume/strength
2. Display of gingival prosthetic junction	2. Inadequate bone reduction
3. Lip incompetence/excessive prosthetic display	3. Encroachment of freeway space
Implant angulation	
1. Instrumentation problem	1. Too mesial
2. Periodontal/endodontic problem	2. Too distal
3. Esthetic problem	3. Too Buccal
4. Tongue encroachment problem	4. Too lingual
Medical comorbidities	
1. Delayed or poor healing/decreased success rate	1. Heavy smokers
2. Infection/decreased success rate	2. Diabetes
3. Failure to osteointegrate	3. Osteoporosis/osteopenia/irradiation
4. Osteonecrosis	4. Antiresorptive medications

9 Virtual Surgical Planning

Some of the greatest changes in contemporary implant treatment, both prosthetic and surgical, involve virtual surgical planning and computer-aided design and manufacturing (CAD/CAM). As previously discussed, cone-beam CT scans allow for

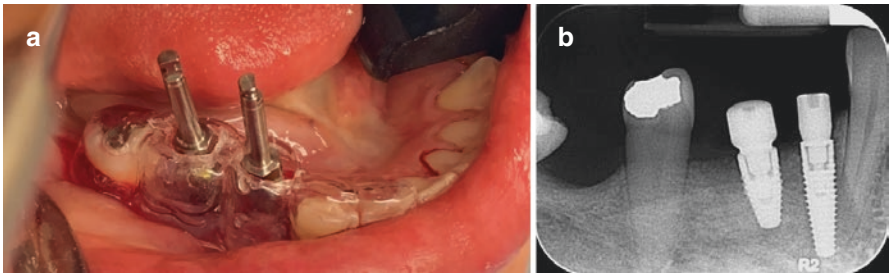


Fig. 5 (**a**) Conventional surgical guide made from dental models, only accounting for the position of the clinical crowns. (**b**) Radiograph showing implant at site #28 in close approximation to the root of tooth #27, as the guide did not adjust for the distal angulation of the canine's root

the evaluation of bone width, adjacent tooth roots, and nearby structures. In addition, several methods can be used to create a virtual impression of the patient's dentition. Using implant-planning software, these CBCT scans and digital impressions can then be used to virtually place implants in their ideal positions. This can be performed in a "crown-down" fashion, beginning with virtually planned prosthetics, which in turn guide the placement of digital implants [30] (Fig. 5).

In addition, proposed implant positions can then be predictably reproduced in vivo via digitally planned implant guides. Traditional implant guides, made off of wax-ups on dental casts, were useful in determining proper implant spacing, but were limited, as they were made from casts that only showed tooth crown positions without data on root positions (Fig. 6). In contrast, virtually designed surgical guides can accurately reproduce planned implant positions, accounting for adjacent roots and vital structures. These guides are virtually fabricated using the same software used for implant planning and are physically produced by either a milling unit (e.g., CEREC, Dentsply Sirona) or a 3D printer (e.g., Planmeca Creo™ C5).

The digital workflow also benefits the restorative provider. The virtual plan can be relayed to dental laboratories to aid in the fabrication of both temporary and permanent prosthetics [31]. This level of predictability minimizes otherwise unforeseen problems. Now more than ever, excellent preoperative treatment planning will increase implant success and minimize complications.

10 Complications and Root-Cause Analysis

As stated, a detailed workup decreases risks and sub-optimal treatment outcomes. However, when complications do occur, identifying the root cause helps avoid the same problem in future cases. Below is a list of common errors that can lead to complications.

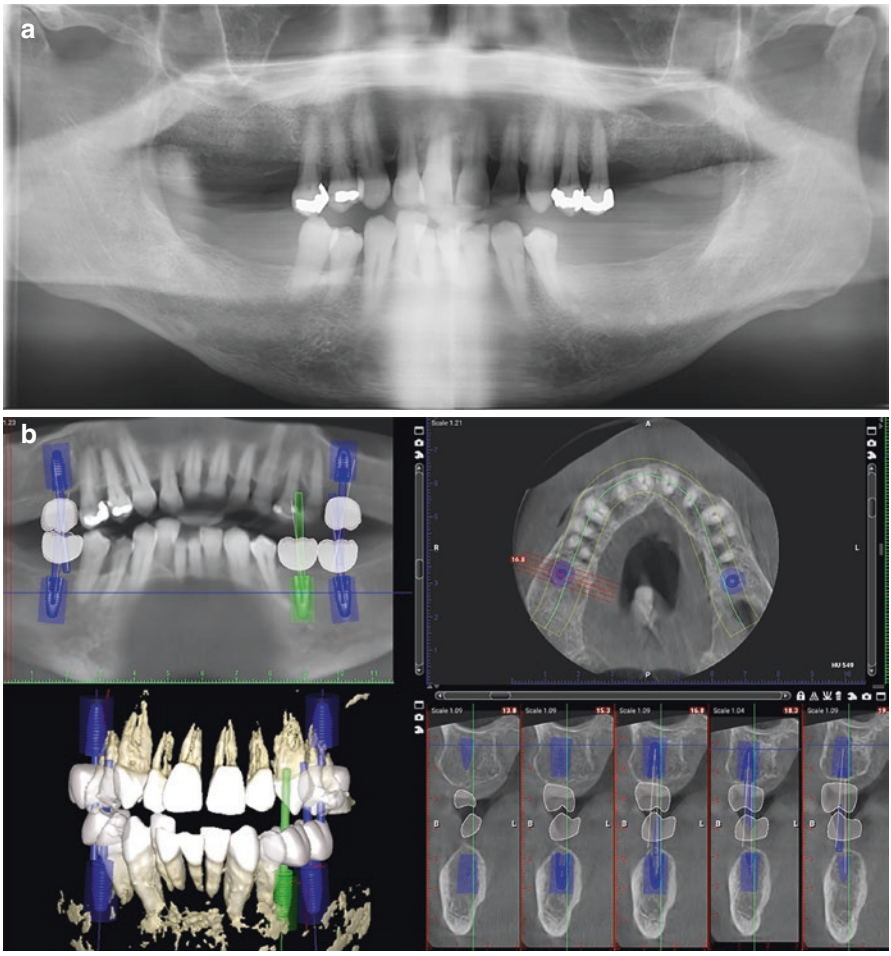


Fig. 6 (**a**, **b**) Digital treatment planning, (**a**) screening panoramic radiograph, (**b**) CBCT with digital software planning ideal implant positions

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Medical Complications in Dental Implantology

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In an age that advancements in medicine are helping patients to live longer, the demands of patients for oral health care that includes the consideration of implant supported prostheses will be extended to an older and more medically compromised population. For example, according to the United Network for Organ sharing (UNOS), more than 36,500 transplants were done in 2018 [1]. Many of these patients return to the work force and most resume their normal daily activities that they enjoyed prior to becoming ill. However, they are all immunosuppressed making them vulnerable to infections. Superb oral health is mandatory in this population and implant dentistry is often part of their oral health care plan. In this population, and others with systemic diseases, consideration for implant supported prosthetics must take into account the benefits and risks of a surgical procedure in addition to the other considerations involved in decision-making for restoration of edentulous areas. Additionally, there are increasing numbers of individuals who have implant supported prostheses that were placed when they were healthy who become ill. For example, women with implant prostheses who are placed on anti-resorptive medications for osteoporosis which developed years after the implants were placed. What challenges do these individuals present to the longevity of their implant dentistry?

The success rate for dental implants is consistently reported at 90–95%. The contraindications to implant surgery are similar to the contraindications to elective

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oral surgery and will be discussed in this chapter. Failure of implants has been reported to be related to infections present at the time of the implant surgery, non-compliance of the patient compliance with oral hygiene, smoking, uncontrolled diabetes and head and neck radiation as factors contributing to failed osseointegration and operator failures including improper placement of the implants and poor prosthetic design [2–8].

Patients with known medical conditions must have their conditions factored into the risk assessment done during the treatment planning phase of their oral health care. This includes in addition to the risks of performing a surgical procedure the additional burden on these patients in maintaining good oral health. This would include those who are neurologically or psychiatrically impaired who will be unable to consistently care for the implant supported prosthesis which is necessary to maintain the health of the tissue supporting the implants.

Of equal importance to the risks of the surgical procedure are the quality of life issues and the cost issues that need to be considered when treatment planning for implants. An example of this is the dilemma of proposing an implant supported prosthetic treatment plan for a patient with a reconstructed mandible following resection and reconstruction with a vascularized fibula free flap followed by radiation therapy for a Stage IV floor of mouth squamous cell cancer. Knowing that the five-year survival rate for these patients is 39%, the treating team must weigh the burden of additional surgery and cost in these medically, emotionally, and financially compromised patients against the improved quality of life restoring the functions that an implant prosthesis will provide for them. This is an example of the ethical issues, which propel the dental treating team along with the entire oncological team to assure that the patient and the family understand what is involved in the successful implant treatment plan.

Given that the majority of patients, with or without systemic disease, will be able to receive implant therapy, this chapter will also explore the areas of concern for bone healing and long-term maintenance of peri-implant tissue health that must be considered when deciding on how best to restore patients with patient-related risk factors that include systemic diseases and the medications used to treat these conditions. These risk factors will be discussed under the headings of the commonly seen categories of systemic diseases.

1 Cardiovascular Disease

There are three different types of patients with cardiovascular disease that we often encounter when treating them for dentistry. Those with structural problem such as valvular disease or replacement, ischemic cardiac disease, and those that have electrical conduction problems. Some of these may lead to heart failure and perhaps the need for cardiac support such as a left ventricular assist device, implanted defibrillator or pacemaker or even transplantation. The cardiac conditions that contraindicate the surgical placement of implants are the same as those that contraindicate any elective surgical procedure and include history of a myocardial infarction within

one month, decompensated congestive heart failure, an uncontrolled atrial or ventricular dysrhythmia, and critical aortic stenosis. Controlled cardiac disease is not a contraindication to implant dentistry in general; however, the medications used to control the condition may require alteration or additional medications added to make the surgical procedure safe. This includes considerations for modification of anticoagulation regimens particularly for mandibular implants that can carry the risk of floor of the mouth bleeding. All alterations in a patient's anticoagulation regimen must be made in consultation with the patient's cardiology team. Patients on warfarin, (Coumadin), should have an INR result within 24 h of the planned implant surgery. INR values of 2.5 or less usually do not result in excessive bleeding from implant placement and the patient can be continued on their scheduled warfarin dosage if risks of discontinuing the anticoagulant therapy are present. If the risk of thromboembolism from the patient's cardiac condition is low, the cardiology team may recommend that the warfarin can be discontinued. The warfarin then is usually discontinued 3 days before the planned implant surgery and an INR value obtained the day of surgery. Depending on the extent of the surgery and the risks associated with postoperative bleeding, the warfarin can be started on the first postoperative day. Patients with high risk of thromboembolism from their cardiac disease, such as mechanical cardiac valves, bare metal coronary vessel stents placed within 6 months of the planned implant therapy, usually will need to stay anticoagulated. If necessary, the patient's anticoagulation therapy can be bridged by discontinuing warfarin 3 days before surgery and starting the patient on low molecular weight heparin (LMWH), which is then held the morning of surgery. Warfarin is started the next day and the LMWH is continued until the INR is again therapeutic. For patients taking low dose ASA daily, there is usually no need to discontinue the ASA. Patient on anti-factor X medications, rivaroxaban (Xarelto), and apixaban (Eliquis), with atrial fibrillation usually can discontinue the medication 24–48 h in advance of the surgery and resume it the day after the surgery. Patients taking antiplatelet medications such as clopidogrel (Plavix), if the surgery is at risk for postoperative bleeding, again with consultation with the treating team, can have the medication discontinued which should be done a week before the planned surgery and restarted the day after surgery.

Antibiotic prophylaxis for implant placement should follow the current American Dental Association (ADA) guidelines [9]. If the patients become disabled after the disease progression begins, and the patient is unable to maintain oral hygiene, periimplantitis can lead to ongoing bacteremias which can further compromise the patient's cardiac disease.

2 Liver Disease

Compromised liver function affects many metabolic systems in patients. Whether from alcohol abuse, hepatitis, or familial inherited diseases, disease progression can result in liver failure. Implant surgery is contraindicated in patients with acute liver disease as is all elective surgery. In these patients and the patients with chronic liver

disease and liver failure, increased potential for bleeding, decreased ability to metabolize medications, and decreased protein (albumin) production leading to immunosuppression can occur.

Antibiotics that are excreted and detoxified by liver will require dosing changes in patients with liver failure and include macrolide antibiotics like erythromycin, azithromycin, and clindamycin. Metronidazole should be used with caution. Caution must be used in considering with pain management in patients with liver failure. Pain management can be challenging. Non-steroid anti-inflammatory drugs (NSAIDs) are usually contraindicated as GI bleeding is a side effect of NSAIDS and life-threatening to patients with liver failure and compromised clotting mechanisms. Opioids can precipitate encephalopathy in these patients. Acetaminophen (less than 2 g/day total dose) and tramadol are reasonable options.

The Model for End-Stage Liver Disease (MELD) score is a value determined by a formula that includes a patient's INR, bilirubin, serum creatinine, serum sodium and whether they are receiving dialysis. Elective surgery can be considered for patients with MELD scores below 10. For scores between 10 and 15, elective surgery is usually contraindicated. Above 15 only emergency life-threatening surgery should be undertaken and there is an associated high mortality rate.

Regarding those patients that have implant supported prosthetics that develop chronic liver failure, there is no evidence available to indicate that liver failure is an independent risk factor in peri-implant bone loss. The patient's oral hygiene must be maintained. Consideration may be given to removing any implant supported prostheses that are difficult to maintain.

3 Renal Disease

There is no absolute contraindication to treating patients with renal disease with dental implants. If in patients with renal failure and on dialysis, the surgery should be done in-between dialysis days. The patients are better rested and not anticoagulated which they are for a period of time during and immediately following dialysis. Kidney transplant patients require controlling for infection. Safe non-opioid options for pain management in the patient with moderate to severe compromised renal function and dialysis patients include acetaminophen, certain NSAIDs, (ibuprofen), hydrocodone, and hydromorphone. Care must be undertaken with the oxycodone which can accumulate and thus the dosing altered. Although there is no consensus, there is some evidence in the literature that NSAIDS can delay the peri-implant bone healing. The protocol for surgical placement of implants includes perioperative antibiotic coverage. Amoxicillin requires increased interval dosing in patients with chronic kidney disease (CKD) with low creatinine clearance values (<30 mL/min nl >60 mL/min). Clindamycin usually requires no changes in dosing.

The patient with existing implants that develops kidney failure, even those needing a transplant can be managed with the thought of maintaining excellent oral hygiene and having prostheses designed to help with the ease of maintenance.

4 Hematological Disease

Patients with hemophilia or thalassemia presenting for placement of implants can be managed with bleeding management plans from their hematology providers in place. Many of these plans can be accomplished at home, thus avoiding the need to hospitalize the patient. The goal for patients with factor deficiencies such as Factor VIII (hemophilia A), and factor IX (hemophilia B), undergoing elective surgery is a factor level of 100%. This may require pre-procedure infusions the morning of the surgery which can take time which must be considered when setting the time of the procedure. For patients with certain types of von Willebrand's disease and mild factor VIII deficiency, desmopressin (DDAVP), either IV, subcutaneously or intranasally is administered preoperatively. Attention to local procedures including careful tissue handling and adequate suturing is essential. Post-procedure management can include home infusions of the deficient factor, administration of DDAVP, scheduled aminocaproic acid, (Amicar) and a very soft diet for 5–7 days.

Patients with hemoglobin counts below 8.5 g/dL, nl range for men 13.5–17 g/dL and for women 12.0–15.5 g/dL should have implant surgery delayed until the etiology of the low value is determined and corrected. Patients with platelet counts below 75–100,000 ml^{-1} or above 450,000 ml^{-1} (normal range 150–450,000 ml^{-1}) should have implant surgery delayed until the etiology is determined and corrected. In the case of a platelet count below 75–100,000 ml^{-1}, elective surgery should be deferred. Careful consideration must be given to recommending platelet transfusions for non-essential surgical procedures.

5 Head and Neck Cancer

Patients with head and neck cancer pose challenges to traditional implant dentistry. Aside from the need to undertake creative designs of the implant prostheses to restore defects that are deficient in soft and hard tissues, these patients often have access issues due to restricted range of jaw motion related to the surgery or radiation therapy, dry mouth related to radiation therapy, or ongoing tobacco or alcohol abuse. Alcohol and tobacco abuse will be discussed in a separate section in this chapter. Radiation therapy, in addition to restricting motion, produces injury to the bone and surrounding soft tissues which are critical factors when considering implant supported prostheses. Tissue supported prostheses also are often unsuccessful as the result of radiation injury and altered oral anatomy. Early after the introduction of osseointegrated implants, radiation therapy to the jaws was considered an absolute contraindication to implant placement. This is no longer true as the literature supports the use of implant supported prostheses to rehabilitate the irradiated patient [10–17]. However, there is still controversy whether radiation therapy is an independent factor in implant failure with more recent literature supporting less difference in outcome in irradiated bone than non-irradiated bone [18–21]. Factors that have been considered when evaluating irradiated patients include the total dose of radiation received, the target for the radiation, the interval of time between the

completion of radiation therapy and the placement of the implants, the use of adjunctive HBO therapy, whether the maxilla or the mandible is being implanted, the concomitant use of alcohol and tobacco by the patient, and the presence of systemic diseases such as osteoporosis and diabetes. Previous literature reported that total radiation dose over 50 Gy may increase the risk of implant failure [12, 22]; however, recent literature supports no difference in implant survival rate related dose of radiation alone [23]. There is some evidence that intensity modulated radiation therapy (IMRT) may have better implant survival rates than conventional conformational radiotherapy [23]. Marx and others, [19, 20, 24, 25], have reported a higher incidence of osteoradionecrosis and implant failure if the implants were placed in the first six months following radiation. A meta-analysis that looked at time interval of implant placement following completion of radiation therapy reported no significant difference between implants placed within the first 12 months and after 12 months [18]. The use of HBO therapy undertaken to promote better implant survival in patients following radiation therapy remains controversial [26, 27].

In summary, with careful selection of patients, meticulous surgical and prosthetic technique, the rehabilitation of a patient can embrace implant supported prostheses which will markedly improve the quality of life for these patients. Care must be taken not to overburden patients and families whose resources emotional and financial are overwhelmed with an implant support prosthetic oral rehabilitation program.

The effects of chemotherapy on tissues are well known. However, there is little information in the literature regarding the effects of chemotherapy on implant healing and survival in head and neck cancer patients. Kovacs reported successful integration of implants when placed 6 months after chemotherapy was completed. He also reported that *cis*-platin or carboplatin and five fluorouracil did not have a negative effect on the survival of mandibular implants [28, 29]. However, the decision to place implants in these patients must be made on an individual basis taking into consideration the condition of the oral cavity, the patient's overall health and resilience, and the patient and families' emotional and financial reserves.

6 Bone Modifying Agents: Anti-resorptives

Anti-resorptive agents have enjoyed widespread use, primarily for the treatment of metabolic bone disease, osteopenia, and osteoporosis, in women and men. Also anti-resorptives are used to treat patients with malignancy involving the bones such as multiple myeloma and in patients with metastatic disease to the skeleton which include breast, prostate, and lung cancer. The relationship between the anti-resorptives and osteonecrosis of the jaws (ONJ) has been well established [30]. However, the relationship between anti-resorptives and dental implants is controversial. Reports of no patients developing ONJ after implant placement and recommendations not to place implants in patients taking anti-resorptives are found in the

literature [31–33]. The decision to place implants in a patient that is receiving or has received anti-resorptive therapy should be made with the patient understanding the risk of ONJ may be present. Some have offered that a drug holiday is indicated and have proposed a 2 or 3 month hiatus from the medication. Any drug holiday decision must be made with consultation with the prescribing team. This is particularly important for those patients that are receiving the medication as part of their chemotherapy for malignancy. In the past it was thought that N-terminal telopeptide (NTX) and amino terminal cross-linked telopeptide (CTX) which are markers for bone turnover found in the blood and used for monitoring anti-resorptive treatment in osteoporosis, would be useful in knowing if and when to place implants in patients taking a drug holiday. The variability of the test and the lack of clinical correlation with outcome have resulted in the adoption of using these markers in the management of patients taking the anti-resorptives and planned for implant placement. Similarly there is no good evidence that any adjunctive therapies such as HBO therapy, pentoxifylline, tocopherol, BMP, and others will decrease the risk of ONJ and implant failure occurring in patients receiving anti-resorptive therapy.

In 2019, the following guidelines were offered by the Multinational Association of Supportive Care in Cancer, International Society of Oral Oncology, and American Society of Clinical Oncology [34].

Medication-Related Osteonecrosis of the Jaw: MASCC/ISOO/ASCO Clinical Practice Guideline Summary.

- Recommendation 2.3 (Elective dentoalveolar surgery). Elective dentoalveolar surgical procedures (e.g., non-medically necessary extractions, alveoloplasties, and implants) should not be performed during active therapy with a BMA (bone modifying agent), *at an oncologic dose*. Exceptions may be considered when a dental specialist with expertise in prevention and treatment of MRONJ has reviewed the benefits and risks of the proposed invasive procedure with the patient and the oncology team (Type: evidence based; Evidence quality: intermediate; Strength of recommendation: moderate).
- Recommendation 2.4 (Dentoalveolar surgery follow-up). If dentoalveolar surgery is performed, patients should be evaluated by the dental specialist on a systematic and frequently scheduled basis (e.g., every 6–8 weeks) until full mucosal coverage of the surgical site has occurred. Communication with the oncologist regarding status of healing is encouraged, particularly when considering future use of BMA (Type: formal consensus; Evidence quality: insufficient; Strength of recommendation: moderate).
- Recommendation 2.5 (Temporary discontinuation of BMAs before dentoalveolar surgery). For patients with cancer who are receiving a BMA at an oncologic dose, there is insufficient evidence to support or refute the need for discontinuation of the BMA before dentoalveolar surgery. Administration of the BMA may be deferred at the discretion of the treating physician, in conjunction with discussion with the patient and the oral health provider (Type: informal consensus; Evidence quality: insufficient; Strength of recommendation: weak).

It should be noted that these recommendations are made for those patients reviewing oncologic doses of BMAs which does not include patients taking lower doses for management of osteopenia or osteoporosis. Also of note the 2014 American Association of Oral and Maxillofacial Surgeons position paper on Medication-Related Osteonecrosis of the Jaws, which does not comment on the risk of developing medication-related ONJ following placement of dental implants [35].

7 The Smoker

Today patients who smoke tobacco and/or cannabis may come for dental implants. The detrimental effects of tobacco use specifically smoking effects not only the overall health of the patient but also the ability of the patient to heal well and maintain dental implants has been well documented. In reviews by Chrcanovic et al. [36], Akfadda [37], and Clementini [38], smoking tobacco was a risk factor in increased marginal peri-implant bone loss and implant failure. In these reviews, the number of cigarettes smoked daily varied and the presence of systemic disease was often a confounder. Clementini [38] reported that the level of evidence, in general, for implant outcome differences in patients with systemic disease is very low, making the higher rate of implant failure in smokers compared to non-smokers significant. The effects of smoking are related to the direct effects of the tobacco smoke on delaying wound healing, the production of peri-implantitis, and the acceleration of the age-related marginal bone loss.

There are currently no publications noted on the use of cannabis and its effects specifically on dental implants in humans. Gda [39] conducted a study on the effects of marijuana smoke on the healing around titanium implants in Wistar Rats. They found decreased mineralization around the implants compared to the control side.

Counselling the patients who smoke on the increased risk of implant failure should be undertaken with emphasis on the detrimental effects of smoking not only being on the immediate period of implant healing, but the long-term survival of the implants [40].

8 Alcohol Consumption

Alcohol has been shown to affect bone healing in the animal model although the mechanisms involved are not clear [41]. In recent studies in humans, excessive alcohol consumption, defined as five or more drinks/day, was observed to result in an increase in implant failure [42]. The results from a study of patients with heavy alcohol consumption revealed an increase in the peri-implantitis rate over a population on non-drinkers [43]. Interestingly, in this study the group with low to moderate alcohol consumption had a lower rate of peri-implantitis than the non-drinking population. The recommendations given to patients regarding alcohol consumption after implant placement should be to limit alcohol intake until the implant healing has been completed and to moderate intake thereafter.

9 Inflammatory Diseases

The management of inflammatory diseases such as rheumatoid arthritis, asthma, and inflammatory bowel disease can result in a vulnerability to infections as well as peri-implantitis. This is also true of many of the inflammatory diseases which are treated with high dose glucocorticoid therapy which has been shown to decrease the rate of bone formation and increase the rate of resorption. There are reports that implants have been lost in patient on long-term high dose corticosteroid use [44]. Soon after the time osseointegrated dental implants were introduced, patients on steroid therapy was one of the contraindications to implant placement [45]. However, studies have not supported increase in dental implant failure in animals administered long-term high dose glucocorticoids [46]. To date there is no clear evidence that steroid therapy affects the long-term success rate for implants. Placing implants into these patients thus is not contraindicated; however, it should be approached with caution. The use of antibiotic prophylaxis, stress dosing of steroids for patients undergoing general anesthesia/deep sedation for the implant procedure and modifications of any medications being used that may compromise wound healing. Careful follow-up and maintenance is necessary to insure a clean healthy oral environment [47].

10 Immune System Dysfunction

Patients with HIV infections, patients undergoing chemotherapy, and patients with autoimmune diseases and organ transplantation will all present with some degree of immunosuppression. The considerations for implant therapy in these patients include the general condition of the patient and the optimization needed for the patient to undergo the implant surgery, considerations for wound healing and medication-related implant failure. Glucocorticoids are used in many of these patients and are discussed above. It is known that HIV affects the osteoblast and osteoclast function and osteoporosis is a common comorbidity in patients living with HIV [48]. Cyclosporine, a commonly used immunosuppressant, has been observed to have effects on bone remodeling in the experimental animal [49]. However, this has not been shown in humans. In a recent meta-analysis of dental implants in immune compromised patients, Duttenhoefer et al. [50] reported the mean survival rate of implants in patients with HIV was 93.1%, those receiving chemotherapy was 98.8%, autoimmune disease was 88.75%, after organ transplantation was 100%. The authors did point out that more investigation is warranted. Their conclusion was no significant effect of immunocompromised conditions on implant survival was detectable. Each patient presenting with immune system dysfunction must be evaluated for surgery and if the benefits of implant therapy are found acceptable, the patient must understand any risks to their underlying condition and all attempts made to optimize the patient for surgery. Commitment to compliance with excellent home care by the patient and maintenance by the surgical and restorative team to avoid implant failure from peri-implantitis must be obtained and documented.

11 Diabetes

The microvascular complications of uncontrolled diabetes delay tissue healing and reduce immune responses. Diabetes is considered a relative contraindication to implant therapy. When poorly controlled, these patients are at risk for poor wound healing of both soft and hard tissues as well as increasing the risk of developing infections. These patients are also at risk of developing chronic inflammation of the gingival tissues around both teeth and implants. The success of implant healing and success in the diabetic patient are thus dependent on glycemic control, as substantiated by a hemoglobin A1c below 7%, elimination of periodontitis, and excellent oral hygiene. The overall implant success rate in well-controlled diabetic patients is reported at 85–90% [51]. For diabetic patients, similar to any elective oral surgical procedure consideration must be given to the need for antibiotic prophylaxis and proper dosing of their hypoglycemic medications. The patient must make a commitment to meticulous oral hygiene and glycemic control. The patient must understand they are at risk for a higher implant failure rate. The restorative team should consider a prosthesis design that incorporates maximum ability to keep clean to minimize the risk of developing peri-implantitis. A strict implant maintenance program is essential. These patients should be seen every 3–4 months by the restorative team.

12 Advanced Age

The population continues to age and live longer. Those that can remain healthy and maintain a good quality of life will become patients that require either placement of dental implants or maintenance of dental implant restorations. Aging increases the occurrence of chronic systemic diseases as well as cognitive impairment and mobility issues. Thus, the ability to care for one's health including good oral hygiene may become compromised as frailty becomes more evident.

With age, salivary flow decreases, leading to dry mouth and mucosal surfaces. Older patients are very likely to be taking multiple medications some of which can also decrease salivary flow as a side effect placing the patient at risk for caries and periodontal disease, including peri-implantitis. In addition, cognitive issues associated with dementia and Alzheimer's diseases may also develop in some patients further compromising the patients' ability to maintain oral hygiene and access oral health care.

Despite these issues, Schimmel et al. [52], reported in a meta-analysis and systematic review, patients older than 75, a 1- and 5-year survival rate of implants similar to younger cohorts. In addition, they propose that advanced age does not seem to negatively affect osseointegration. Additionally they reported that patients receiving radiotherapy for cancer and high doses of anti-resorptives for bone metastases are at risk for higher implant failure rates.

13 Neurologic and Musculoskeletal Deficits Patients

Schimmel et al. [52] did not find neurological diseases in themselves negatively affected implant survival. However, the patient with neurologic and or musculoskeletal diseases may pose challenges related to cognition, the ability to understand, as well as weak or compromised motor function and decreased ability to support good home care. Diagnoses such as stroke, Alzheimer, and dementia may all compromise the patient's ability to understand how to care for themselves and they may be subject to the care of a family member or an aid. The ability to also be able to use their arms and hands effectively may also be compromised. With muscular dystrophies and cerebral palsy the patient is known to have these musculoskeletal limitations and prostheses design will have to be modified, so that they can be cared for appropriately. A more frequent maintenance program will be necessary to manage this type of patient.

A factor that should be considered with patients with neurological diseases is the possibility of the existence of clenching and bruxing, which can lead to implant failure including fracture of the prostheses as well as fixtures. If the patients are physically unable to wear a stress breaking appliance, then implants should not be done.

14 Psychiatric Disorders

Wu et al. reported in a retrospective cohort study that patients taking SSRIs for depression had an increased risk of implant failure [53]. They proposed that this resulted from the inhibition of bone remodeling by SSRIs. Many of the psychiatric medications will produce a decrease in salivary flow, which can lead to increased peri-implantitis. Any psychiatric disorder that results in the patient's inability to maintain oral hygiene, results in excessive smoking or heavy alcohol use will result in a higher implant failure rate.

15 Conclusion

In the patient with systemic disease, risk stratification must be undertaken for each patient assessing the risks of the surgery and ability of the patient to maintain the planned implant supported prosthesis. Current evidence supports high implant survival rates in most patients with systemic diseases when co-risk factors which include smoking, periodontitis, and poor oral hygiene are removed. Evidence does support a higher implant failure and incidence of peri-implantitis in patients having received radiation therapy for head and neck cancer, high doses of anti-resorptive therapy for osteoporosis, multiple myeloma or metastatic cancer to the skeleton, and poorly controlled diabetics. Heavy alcohol consumption also appears to lead to

a higher implant failure rate. A thorough medical history, knowledge of the patients' medications and schedule, optimization of the patient for the surgery, consulting with the patient's medical providers and assuring the patient understands when there are increased risks, and the absolute need of excellent oral hygiene can lead to implant healing and similar high survival rates seen in healthy patients.

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Intraoperative Dental Implant Complications

Behnam Bohluli, Seied Omid Keyhan, Behzad Cheshmi, and Christopher Ward

1 Introduction

The placement of dental implants has been a growing trend over the past two decades. It is estimated that more than 300,000 dental implants are placed annually in the United States. Overall, the placement of dental implants is considered a safe and effective treatment modality, with success rates higher than 98% quoted in current literature [1]. With both specialists and general practitioners placing more implants, the rate of complications seems to be increasing. Complications can occur in any phase of dental implant therapy, including the preoperative planning phase, intraoperatively, or postoperatively (even several years after the initial placement). [2–5].

Complications associated with the preoperative and postoperative stages of implant placement have been thoroughly discussed in the literature. However, less attention has been spent on addressing intraoperative complications and subsequent management [6]. This chapter will focus on more significant intraoperative complications that may arise during implant placement surgery.

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2 Aspiration or Ingestion of Implants and Their Associated Components

Historically, aspiration or swallowing of implants and implant components has been a significant concern in implantology. Branemark proposed tying pieces of dental floss to each implant component when feasible to have better control and retrievability [7]. *Despite implementing procedures to mitigate this complication, it seems that the potential risk of aspirating or ingesting these small objects often goes overlooked by practitioners.*

The small space of the oral cavity combined with the presence of saliva and blood makes it increasingly easy to lose grip of implant components. This environment, combined with the small size and dexterity required to control these components, increases the risk of them falling into the oropharynx [8]. Previous studies have reported that instruments are aspirated into the pulmonary system in only 13% of the cases, while the remainder are swallowed [9–12]. The sharp nature of some of these instruments also has the potential to cause further injury to the gastrointestinal or respiratory systems [9]. Additionally, there is always the inherent risk of the foreign body causing airway obstruction, which can be life-threatening [12]. In cases of complete obstruction, immediate removal of the foreign body is necessary to allow for adequate air entry into the lungs [12, 13]. Aspiration events also require a prompt referral of the patient to an otolaryngologist for a definitive examination of the airway and retrieval of the foreign body if necessary. When a foreign body enters the airway, the main symptom is generally coughing, although it may be asymptomatic [14]. Following the ingestion of a foreign body, it is necessary to obtain a chest X-ray and possibly an abdominal X-ray to identify its location (Fig. 1). It is a common misconception that if aspiration has been ruled out with a chest X-ray, then no further follow-up with the patient is required. However, active follow-up is necessary to ensure that the object has passed through the digestive tract. It may be

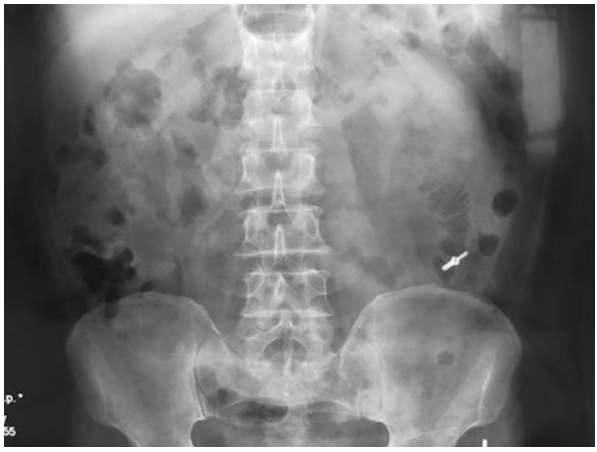

Fig. 1 When an implant component is swallowed, X-ray should be taken to make sure it is excreted or not. In this patient, a parallel pin has been stuck in abdomen that needed medical intervention

appropriate to refer the patient to a gastroenterologist for assessment and further management if the object does not pass through the digestive tract. Munter believes that when a foreign body less than 20 mm in size is ingested, the chance of it clearing the gastrointestinal tract without complications is over 90% [15].

Critical points in the prevention and management of ingestion or aspiration of implants and implant instruments:

- Practitioners should not overlook the possibility of swallowing or aspirating dental implants or their associated components.
- It is best to identify patients who are at high risk for aspiration preoperatively and ensure proper protocols are followed to minimize the risk of intraoperative aspiration.
- The patient should be repeatedly informed not to make sudden movements (if not under sedation) when using delicate components or instruments that can fall inside the mouth.
- Both aspiration and ingestion of implant components require confirmation with the appropriate radiographs; initiate referrals to the proper medical specialists when needed.

3 Inadequate Stability and Displacement

The need for primary stability has historically been considered a prerequisite for optimal osseointegration ever since Branemark first described the concept in 1969. It is generally accepted that an initial amount of implant stability is required to help bone healing and to prevent implant displacement during the healing process. Inadequate primary stability is one of the most common intraoperative complications that can lead to immediate or early implant failure. A more substantial complication arising from lack of primary stability is displacement of the implant into surrounding marrow or fascial spaces (Figs. 2a, b and 3) potentially damaging adjacent vital structures such as nerves (Fig. 4) [16]. Many factors can contribute to poor primary stability, including reduced bone quality [17], overpreparation of the osteotomy site by the surgeon, and placing an implant into a

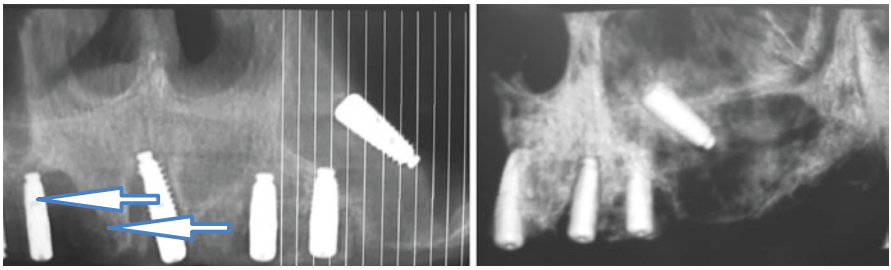

Fig. 2 Inadequate primary stability may lead to early failures that may lead to (**a**) early implant failures (arrows) or (**b**) implant displacement to adjacent tissues

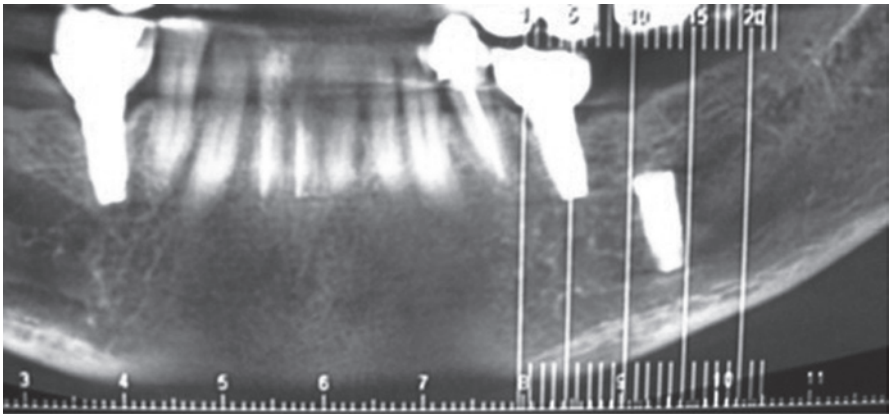

Fig. 3 Implant displacement to submandibular space due to inadequate stability

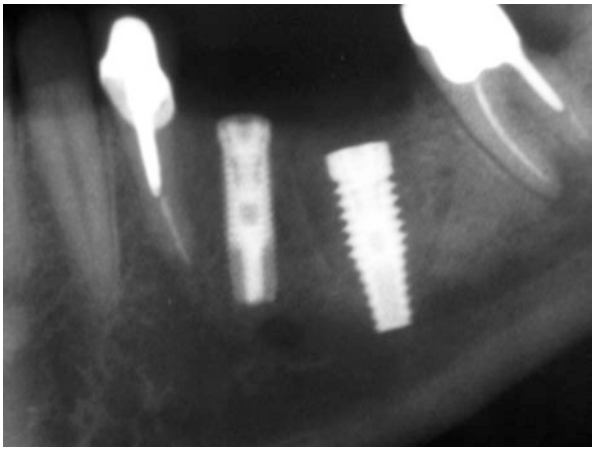

Fig. 4 A practical way to improve inadequate stability is to submerge the implant for 1–2 mm. This maneuver is to be used cautiously with considering adjacent tissues. Here, 2 mm intrusion has caused direct inferior alveolar nerve damage

site with inadequate surrounding bone [18]. This scenario can occur when an implant is placed immediately into an extraction socket with a mismatch between the diameter of the implant and the amount of available bone [19]. If primary stability is not achieved, the surgeon needs to consider all contributing factors, such as reduced bone volume and quality. If the surgeon opts to alter the position of the implant or to place it deeper into the site, the proximity of adjacent anatomic structures needs to be taken into consideration. Deeper insertion of the same implant or the use of a larger implant (in terms of length or width) can be used when feasible. Otherwise, it may be best to remove the implant and reschedule the patient to explore other treatment options [20].

Factors that may aid in implant stability include the use of sharp drills, controlled speed, and continuous cooling of the area using an isotonic fluid (such

as normal saline). An increase in temperature caused by friction from fast and continuous drilling can lead to necrosis, fibrosis, osteolytic degeneration, and an exacerbation of osteoclastic activity [21]. The extent of necrosis is directly related to the rate of temperature increase in the area. Erikson and Albrektsson stated that the maximum temperature that bone can tolerate without causing necrosis is 47 °C. However, even at lower temperatures, continuous drilling without irrigation can result in bone resorption of up to 20% over the following 30-day postoperative period [22, 23]. Furthermore, there is no consensus regarding which irrigation method is superior at cooling of the osteotomy site. Benington et al. suggested that there is no significant difference between the internal and external irrigation systems [24].

One of the more severe complications that can occur from a lack of primary implant stability in the maxilla is the displacement of the implant into the sinus or nasal cavity. Factors that may contribute to this include inadequate maxillary bone, poor preoperative treatment planning, and lack of surgical experience. Generally, it is possible to prevent such complications by respecting adjacent anatomy, proper preoperative planning, and appropriate follow-up after surgery [25].

Key points in the prevention and management of inadequate primary stability:

- Placement of a rescue implant with a larger width or length may be used when there is enough surrounding bone, and no anatomic limitations.
- If any limitations (anatomic or restoratively related) are encountered, it is better to remove the unstable implant and re-attempt placement after osseous healing is complete.
- If an implant becomes displaced, it can be retrieved if there is adequate visualization. However, if initial attempts fail, further failed attempts may lead to more severe complications. Referral to an experienced oral and maxillofacial surgeon is recommended in this scenario (Fig. 5a–f).

3.1 Malpositioned Implants

Anatomic factors such as alveolar ridge deficiencies, an unharmonious occlusal plane before implant placement, and heterogenous bone density can all contribute to poor implant angulation. Operator errors such as failure to seat a surgical template properly, as well as a lack of three-dimensional perception for the final prosthesis angulation, can also be a source of error [20, 26, 27]. Reversing out an implant to correct the final position and angulation can be done manually or with the aid of a side-cutting Lindemann drill. However, removing an implant to correct an angulation error and repositioning it or replacing it with one of similar size will create a space between the implant and the bone. The diameter of this gap can range from 0.35 to 1.25 mm but disappears as bone fills the region. Therefore, if adequate initial stability is achieved, this gap may not affect the long-term results of implant placement [28].

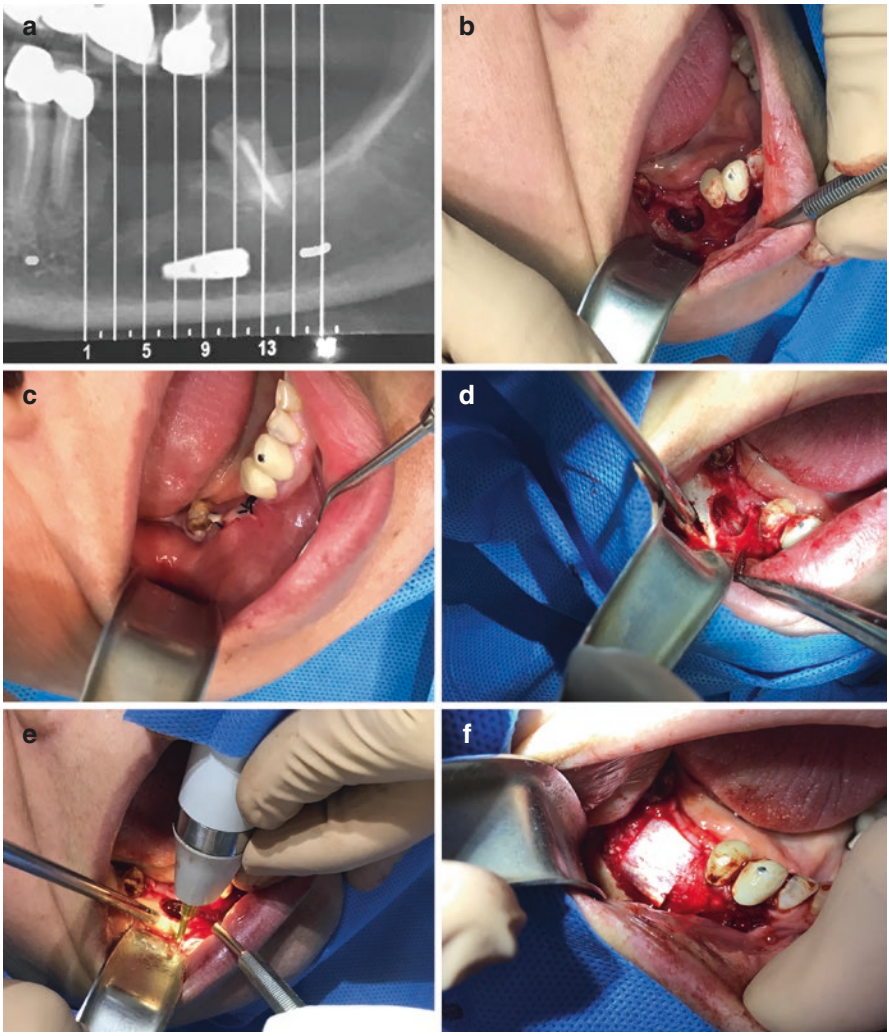

Fig. 5 Implant displacement. (**a**–**c**) Implant is disappeared in osteotomy site. Primary efforts fails to find and retrieve implant. (**d**) A wide flap is raised. (**e**) A window is created by piezo appliance. (**f**) Implant is retrieved, nerve is repaired

4 Damage to Adjacent Teeth

Damage to adjacent teeth may occur when implants are placed adjacent to natural teeth. Contributing factors include an inadequate distance between the implant site and adjacent teeth, inappropriate angulation of the implant, and thermal injury from drilling. Tooth vitality can be partially or entirely lost as a result of one or more of these factors [29]. Although patients will initially be asymptomatic, pain or sensitivity

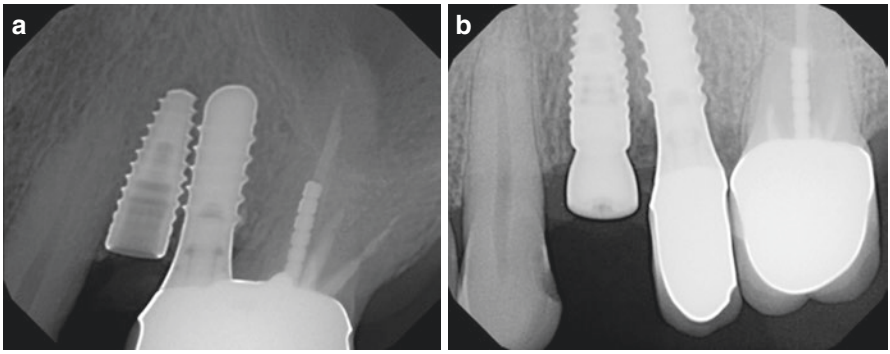

Fig. 6 Damage to adjacent teeth. The first step is to take radiographs in different angulation. (**a**) A suspicious tooth damage is ruled out 5, (**b**) by taking a second X-ray in different angulation

is likely to develop over time. Maintaining a minimum distance of 1.5–2 mm between the implant site and the adjacent tooth is necessary for both preservation of surrounding crestal bone and reducing the likelihood of these complications. The use of CT and CBCT diagnostic imaging for proper and accurate treatment planning also plays a significant role in preventing iatrogenic damage to surrounding teeth and vital structures. In the event of such an injury, root canal treatment, apicectomy, or extraction are some of the possible treatment modalities that may be required, depending on the diagnosis and prognosis of the affected tooth [30].

Key points in the prevention and management of adjacent tooth damage:

- Thorough preoperative evaluation of the implant site for adjacent root curvature and other anatomic variations may help avoid this complication.
- Surgical guides are recommended for use in even single tooth rehabilitation sites with complex local anatomy.
- -If adjacent tooth root damage is suspected, periapical radiographs from multiple angulations may aid in diagnosis (Fig. 6a, b).
- In the scenario of proven root damage, explantation of the fixture and placement of a new endosseous implant, or delayed surgery may be the best available treatment options.

5 Mandible Fracture

Jaw fractures are a relatively uncommon but severe complication in implantology [31]. Several factors, such as osteoporosis, tensile stress accumulation at the implant site, and trauma during implant placement, can all contribute to mandibular fractures. Implant-related factors such as the length and diameter of the implant can also add to this complication [32, 33]. The risk of mandibular fracture from implant placement is particularly high in elderly patients who often possess atrophic mandibles. Placement of implants in already compromised osseous structures will further weaken the remaining cortical bone leading to increased risk of fracture. Pre-prosthetic surgeries such as inferior alveolar nerve lateralization also increase

the risk of mandible fracture, due to the inherent loss of cortical bone structure associated with this procedure. The prevalence of jaw fractures among edentulous patients following implant placement is reported at a frequency of approximately 0.2% [34]. It should also be noted that mandibular fractures do not necessarily occur during implant surgery and may sometimes precipitate in the postoperative period. Karlis et al. indicated that it is sensible to stabilize implants by engaging the inferior border to increase primary stability, as long as the integrity of the inferior border is maintained [35]. The surgeon must assess the plausibility of the residual bone being able to accommodate both endosseous implants and the compressive and tensile forces normally placed on the mandible (70) [36]. Park and Wang believe that at least 7 mm of height and 6 mm of residual bone width is required for implant placement in an atrophic mandible [37]. If this complication arises, mandibular fracture management depends on its severity, the amount of remaining bone, and the location of the fracture. The degree of displacement seems to be the most crucial factor in choosing the most appropriate treatment modality. In cases with minimal mobility or displacement, the implant does not need to be removed and can be maintained in the fracture site. In cases of significant mobility and bony displacement, the surgeon needs to consider both the appropriate management of the fracture (usually requiring an open approach) and the need for implant removal from the fracture site (Fig. 7a–d). Raghoebar GM et al. reported that in cases of mandibular fracture

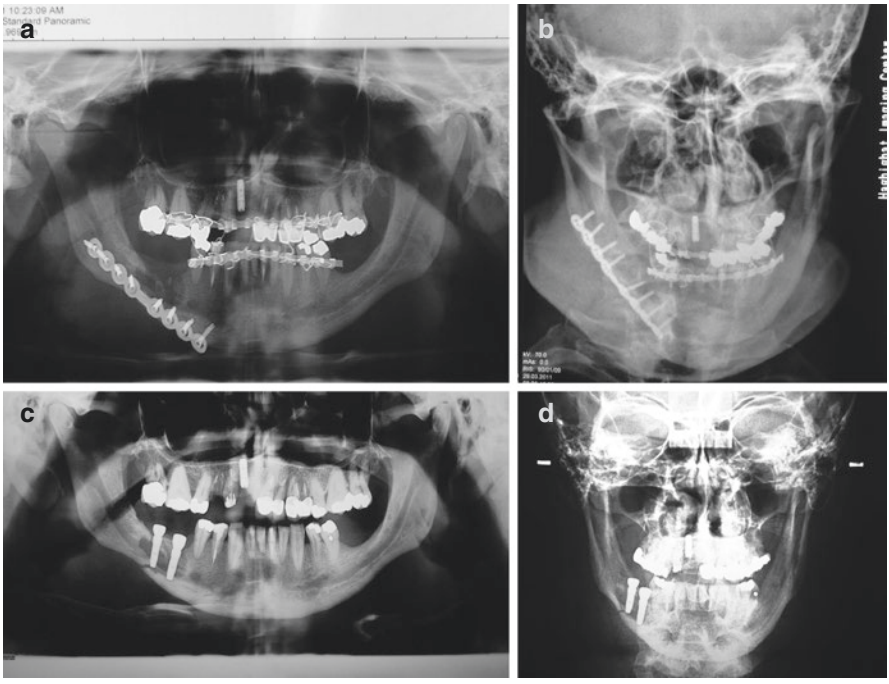

Fig. 7 (**a**, **b**) Mandibular fracture after implant placement. (**c**, **d**) Treatment of the fracture by AO plates and extraoral approach

during implant placement, bone grafts in combination with rigid fixation were needed in three cases for full resolution, while rigid fixation with osteosynthesis plates was only successful in one case [38]. Critical factors that can detect and prevent such complications are regular clinical and radiographic follow-up and instructing the patient to avoid excessive occlusal forces during the osseointegration phase.

Key points in the prevention and management of jaw fractures:

- Susceptible patients, such as patients with severely atrophic jaws, require thorough preoperative radiographic and clinical evaluation. All potential anatomic and systemic risk factors (osteoporosis) increasing the risk of mandible fracture should be identified and explained to the patient as part of the informed consent process.
- Excessive force is never required during exodontia or implant placement. The use of excessive force is almost always associated with a technical flaw that is best corrected before severe complications arise.
- Patients with suspected mandible fractures after implant placement need to be evaluated clinically and radiographically. Confirmed fractures need to be referred to oral and maxillofacial surgeon for definitive management.

6 Insufficient Inter-implant Distance

An adequate amount of mucosal thickness between the two neighboring implants is required to form a proper epithelial connective-tissue attachment [39]. If the mucosal thickness between the two adjacent implants is unsatisfactory as a result of insufficient inter-implant distance, crestal bone will resorb to establish adequate space for the connective-tissue attachment to form a proper biological width [40]. One of the main factors in the formation of a well-shaped papilla around an implant is its distance from the adjacent tooth or implant [41, 42]. As noted, one of the significant consequences of insufficient space between the two adjacent implants is the increased risk of crestal bone resorption in the area. The leading cause of this complication is an increase in osseous remodeling in the area. In other words, as each implant experiences crestal bone loss in its proximity, placing two implants in a close relationship can exacerbate the condition leading to significant bone loss. One of the most undesirable esthetic consequences of severe bone resorption in the crestal area between the two implants is papilla recession and “black triangle” formation [43, 44]. Crestal bone resorption will increase the distance between the contact point of the crowns and the bone level. If this length increases to more than five mm, it will cause the papilla to shrink in size and contour [45]. Studies have indicated that inter-implant distance less than 3 mm will cause 1.04 mm of interproximal bone loss, whereas if this distance is greater than 3 mm, the resorption will be reduced to 0.45 mm [46]. Therefore, based on these findings, it can be stated that the ideal inter-implant distance to avoid interproximal bone resorption is more than 3 mm. However, the results of a recent systematic review study demonstrated that the optimal distance between implants has not yet been entirely determined and requires further investigation [47].

7 Nerve Injury

Nerve injury can occur for a variety of reasons, including poor flap design, mechanical injury, hematoma, over-preparation of the implant site, nerve transposition, and placement of an implant in an atrophic jaw [48–50]. Neurosensory disturbances are classified into three major categories in terms of severity: neurapraxia, axonotmesis, and neurotmesis. Neurapraxia is a mild type of nerve damage that can occur as a result of compression or traction of the nerve, and given that the axon remains intact in this condition, it is usually only associated with a transient lack of sensation that is regained in approximately 4–6 weeks. Severe compression or traction of a nerve can lead to axonotmesis, causing ischemia, intrafascicular edema, or demyelination of the affected nerve. In this situation, although the overall structure of the nerve remains intact, some damage to the axon will be detectable. Small improvements in sensory perception begin around the fifth week after surgery and can continue for 10 months.

The most severe form of nerve damage is neurotmesis, in which nerve disruption occurs, and no impulse is transmitted across the nerve. Despite the use of microsurgical techniques such as neurorrhaphy after nerve transection, the prognosis of nerve healing is not promising. Sensory disturbances that occur immediately after the surgery can be reported by the patient in the form of anesthesia, hypoesthesia, paresthesia, or dysesthesia. Nerves that can be inadvertently damaged during the implant surgery process include the inferior alveolar nerve, the lingual nerve, the mental nerve, the incisor branch of the mandibular nerve, and the nasopalatine nerve. Factors that can particularly affect the inferior alveolar nerve are lateral transposition of the nerve, hematoma formation as a result of surgery-related bleeding, and excessive drilling for implant placement. Injury to the inferior alveolar nerve during nerve transposition can lead to sensory disturbances in the incisor and mental region. The lingual nerve can be damaged as a result of an inadvertent injection, poor flap design, or an aggressive flap elevation. To prevent such problems during implant surgery, careful preoperative evaluation and accurate identification of the inferior alveolar nerve pathway using appropriate radiographic techniques including CT and CBCT are essential. Insertion of an implant at least 5 mm away from the mental foramen and at least 2 mm away from the mandibular canal is considered safe and conservative. One approach to minimize the complications of nerve injury is to assess the implant site radiographically immediately after surgery. If the operator detects invasion of the implant into the nerve canal or the loss of the integrity of the nerve pathway, he/she will immediately notice the injury and take appropriate action. Medications often utilized in the setting of a nerve injury during implant surgery include anti-inflammatory drugs and vitamin B. However, if sensory disturbances persist, more specialized interventions such as microsurgery may also be used. If the patient complains of paresthesia, even though the implant is positioned correctly and there is no evidence of nerve damage, it is reasonable for the surgeon to postpone any immediate intervention and monitor the patient's symptoms. In other words, implant removal is not recommended if osseointegration is achieved, and no evidence of direct nerve injury is found on further radiographic investigation [50] (Fig. 8a–f).

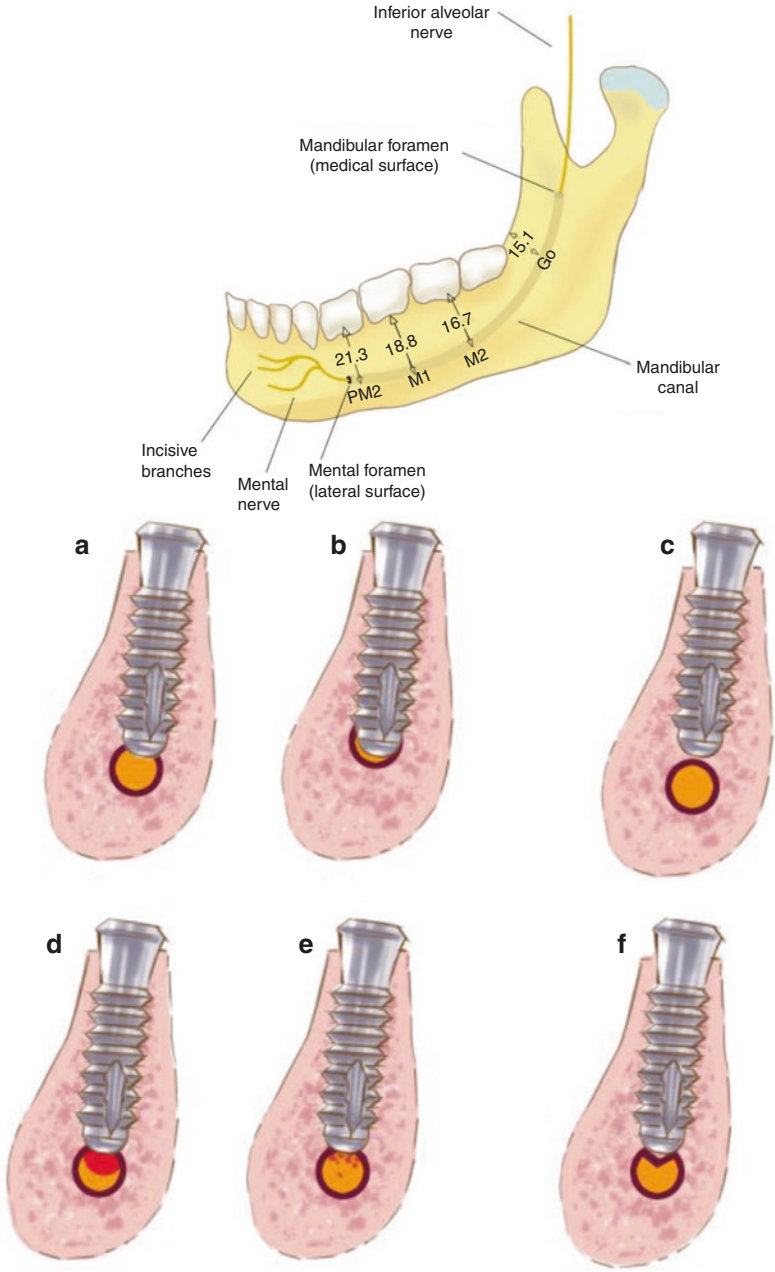

Fig. 8 (**a**) Partial implant intrusion into mandibular canal can cause direct mechanical IAN trauma—encroach, or laceration and primary ischemia. (**b**) Full implant intrusion into mandibular canal can cause direct IAN transection, and/or compression and prsimary ischemia. (**c**) Dental implant is too close to the mandibular canal; it can cause IAN compression. (**d**) Partial implant intrusion into mandibular canal can cause indirect trauma due to hematoma and secondary ischemia. (**e**) Partial implant intrusion into mandibular canal can cause indirect trauma due to bone debris and secondary ischemia. (**f**) "Cracking" of the IAN canal roof by its close

8 Hemorrhage: Bleeding

A defect in the wall of a blood vessel can lead to a significant loss of blood, resulting in the formation of a large clot in surrounding the tissue or anatomical spaces. This process is generally referred to as hematoma. The accumulation of blood or any other fluid outside the vessels can lead to the formation of a rigid and palpable mass. Although minor bleeding can be considered a complication and may be stressful for the surgeon due to its nature, it is not usually considered a life-threatening complication [51, 52]. A severe hemorrhage can result from injury to an artery during a sinus lift procedure or from the drills used in preparation of the implant osteotomy site. The arteries that can cause significant hemorrhaging in the maxilla include the posterior-superior alveolar, infraorbital, descending palatine, and posterior palatine arteries [53] (Fig. 9). Placement of 15–20 mm length implants in the retromolar trigone of the maxilla, or the pterygoid apophyses, can damage the posterior palatine artery and lead to hemorrhage [54] Given the high risk of vascular injury in this area with the use of drills for implant placement, the use of the osteotomes appears to be a more conservative approach that reduces the chance of this complication [55]. Although exceedingly rare, intraocular hemorrhage resulting in a sudden loss of vision has been reported after implant placement procedures in the maxilla. Krepler et al. reported a case where an intraocular hemorrhage was precipitated in a hypertensive patient by applying a Valsalva maneuver following implant placement in the maxilla [56]. Branches of the facial and maxillary arteries are generally the primary blood supply of the lower jaw. The sublingual and submental arteries are major suppliers of the oral floor vascular network [57]. Hemorrhage caused by damage to the mylohyoid artery usually occurs in the posterior, lingual, and mandibular area. However, it can often be controlled by applying finger pressure on the bleeding point, or along the lingual mandibular region distal to the roots of the third molar [58]. Any efforts to ligate this artery are often unsuccessful, and surgical exploration to identify the source of hemorrhage can make the condition more critical [59]. If firm digital pressure on the inferior medial mandibular border stops the observed hemorrhage, the submental or facial artery is likely the source of the bleeding [60]. In this case, the surgeon should consider surgical ligation as a treatment option [61].

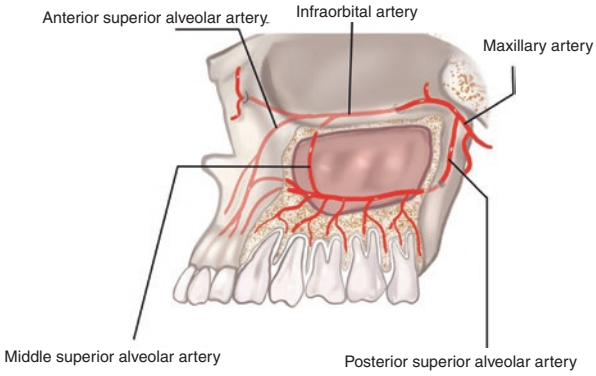

Fig. 9 Maxillary blood supply network

If the previously mentioned ligation, in combination with finger pressure on the area, does not achieve hemostasis, ligation of the lingual artery is the next treatment option. Given the possibility of vascular anastomoses between the facial and lingual arteries, some scenarios may require simultaneous ligation, depending on the surgeon's diagnosis. In general, hemorrhage arising from small and terminal branches of arteries can be managed by ligation, digital pressure, vasoconstrictor injection, or a combination of these methods [59]. Elevation of the tongue and floor of the mouth and subsequent airway obstruction as a result of bleeding are known as the "pseudo-Ludwig phenomenon" [62]. Impending airway obstruction is managed with nasotracheal intubation, cricothyroidotomy, or a tracheostomy [63]. Other treatment options available to manage hemorrhage include bone wax, manual compression, electrocoagulation, bone grafts, and ligation of the vessels in severe cases. Due to the tamponading effect of the blood clot, aspiration is not recommended as a treatment option in the literature [61]. In cases of limited visibility and access, external carotid angiography and endovascular techniques can be utilized to achieve hemostasis [62]. Having a proper understanding of anatomy, as well as appropriate treatment algorithms for the management of emergent hemorrhages, is crucial for ensuring patient safety [64]. Additionally, preoperative CT and CBCT images can be used to gain some three-dimensional understanding of the underlying vascular pathways to prevent injury. Careful and conservative management of the soft tissue can also prevent hemorrhagic events. For this reason, long vertical releasing incisions should be avoided when possible, as they can transect vessels [65]. During flap elevation, the elevator should remain on bone, without excessive pressure being directed into the adjacent soft tissues. However, applying transient pressure to the tissues in the surgical area will aid with hemostasis, ultimately reducing the size of the blood clot. Furthermore, perforation of the lingual mandibular cortex can be prevented by holding the drill parallel to an elevator placed in the lingual subperiosteal plane [66]. The application of ice or cold-packs for 24–48 h postoperatively can aid with vasoconstriction, limiting the size of potential hematomas and decreasing post-surgical edema. Cold-packs and ice application can be followed by heat after 48 h to improve vasodilation, facilitating blood flow out of the area [8] (Fig. 10).

Perforation of lingual plate and invasion into submandibular space during implant placement in the posterior mandibular region.

Implant placement in the anterior and posterior mandibular region should be performed with caution if resorption in the submandibular or sublingual area is noted on radiographic exam. Resorption in these regions may produce an undercut, increasing the potential risk of lingual plate perforation (Fig. 11). The formation of a hemorrhage in the posterior zone of the mandible is one of the inadvertent consequences of lingual plate perforation. In anatomic studies, 2.4% of evaluated mandibles had lingual concavities with a depth of more than 6 mm [67]. Primary interventions in the event of hemorrhage secondary to inadvertent perforation of the lingual plate include repositioning the patient into an upright position and applying digital pressure to the affected area [45]. Since bleeding and hematoma formation in the submandibular space can cause tracheal deviation [68], airway assessment is also essential to ensure that ventilation is maintained.

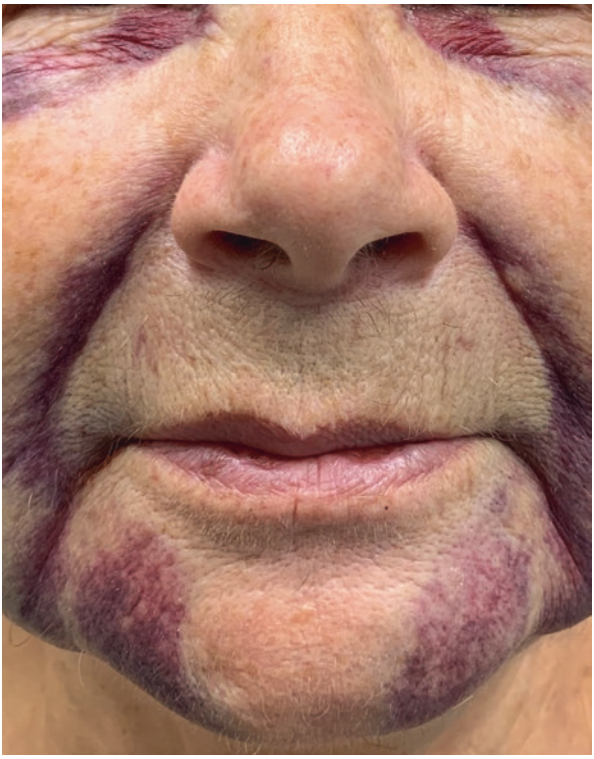

Fig. 10 Diffused ecchymosis after full mouth implant reconstruction

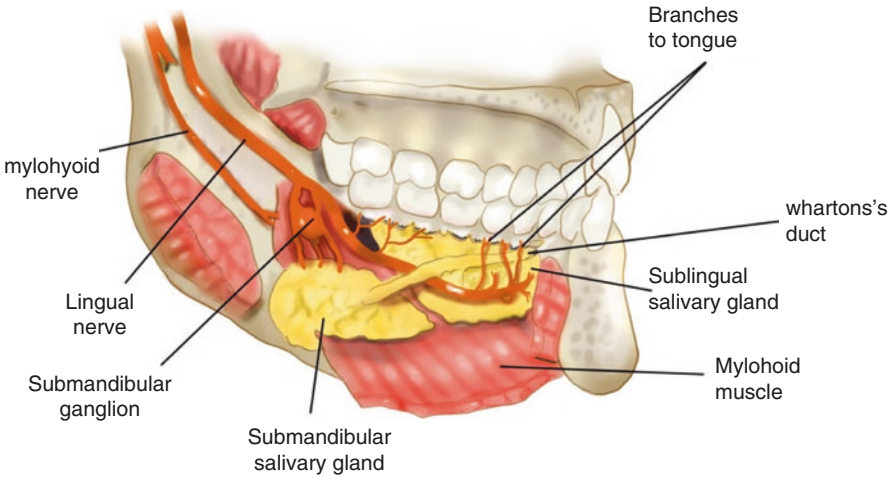

Fig. 11 Anatomy of a number of critical organs that can be damaged during implant placement in mandible

Invasion of the implant to the glandular structures located in the posterior mandible, including the salivary glands and salivary ducts, can lead to the formation of ranulas in the floor of the mouth [69]. If a ranula is small and asymptomatic, no surgery or marsupialization is needed. However, larger ranulas often require surgical intervention for resolution, requiring removal of the associated salivary gland by an oral and maxillofacial surgeon [13]. Similar to preventing iatrogenic damage to other vital structures mentioned previously, the best strategy in preventing injury to the salivary glands is thorough preoperative treatment planning. Obtaining preoperative CT or CBCT images gives the surgeon the ability to formulate a prosthetically driven treatment plan while ensuring the implant location and angulation does not invade or damage adjacent anatomical structures.

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Anatomic Basis of Dental Implant Complications

Marco F. Caminiti and Justin Kierce

1 Introduction

With any surgical procedure, including the placement of dental implants, an intricate knowledge of anatomy is crucial to minimize the risk of complications. While the anatomy of the head and neck is complex, this chapter will highlight some of the key structures to be aware of that may be implicated in various dental implant related complications. Having a thorough understanding of the appropriate anatomy will allow the practitioner to minimize the risk of sensory deficits, bleeding, implant displacement, fractures, and infections. The anatomic insults can be divided into five structural categories:

1. Vascular injuries.
2. Neurologic injuries.
3. Osseous and dental Injuries.
4. Soft tissue injuries.
5. Injuries which involve spread to fascial spaces.

These structures may be injured either directly or through indirect effects such as hematoma formation. With the appropriate knowledge of the anatomy outlined in this chapter, as well as with proper planning and surgical technique, practitioners will have an appropriate anatomical foundation to minimize potential injuries.

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2 Vascular Injuries

A basic review of the vascularity of the head and neck is required in order to understand the complexity of the blood supply and where injuries can occur. Vascular injuries can be divided into four different categories depending on the type of vessel and degree of damage, as follows:

1. Acute arterial brisk bleeding.
2. Venous/vascular bed bleeding.
3. Soft tissue inconspicuous bleeding.
4. Hematomas.

The blood vessels of the head and neck are also rich with contralateral and ipsilateral anastomoses; therefore, even with cautery, ligation, or embolization, these vessels have the potential to regain blood flow in short amount of time. Embolization of a vessel is generally effective for 48–72 h before collateral blood flow to the area is established.

2.1 General Blood Supply to the Head and Neck

The facial region receives its main blood supply from branches of the external carotid artery, and to a lesser extent from the ophthalmic artery (which is a branch of the internal carotid artery). The common carotid artery branches into the external and internal carotid arteries near the superior border of the laryngeal cartilage [1]. The internal carotid artery generally does not give off any branches until it reaches the cranial fossa. The external carotid artery gives off eight main branches that supply the head and neck region which are outlined in Fig. 1 and Table 1 [2]. We will discuss the facial, lingual, and internal maxillary branches in more detail as they are more directly involved with the blood flow of the maxillomandibular region.

The branches of the facial artery can be divided into two groups: the cervical and facial branches. Of the cervical branches, the ascending palatine is significant in providing blood supply to the maxilla. The main branches of the facial artery that terminate on the face are the inferior labial artery, superior labial artery, lateral nasal, and the angular artery as depicted in Fig. 2 [2].

The lingual artery provides the major blood supply to the tongue. It ascends though the neck and passes deep to the hyoglossus muscle. The lingual artery has four main branches: the suprahyoid artery, the sublingual artery, the dorsal lingual artery, and most terminally the deep lingual artery. The dorsal lingual artery supplies the root of the tongue and the palatine tonsils, whereas the deep lingual artery provides the main blood supply to the tongue. The sublingual branch provides the main blood supply to the sublingual gland, the mylohyoid muscle, as well as the mandibular gingiva [3]. Any surgery within the floor of the mouth should be approached with caution due to potential damage to this rich vasculature, as well as to the submandibular duct. Once vascular injury has occurred in this region, it is often difficult area to achieve hemostasis.

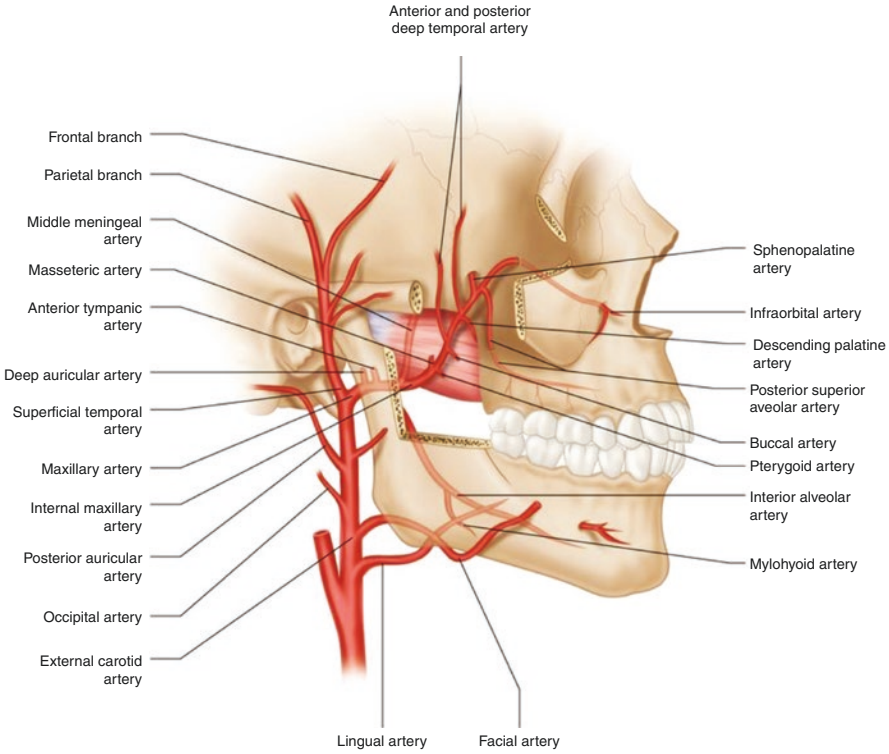

Fig. 1 An illustration of some of the main branches arising from the external carotid artery (From Wexler A.M. (2015) Anatomy of the Head and Neck. In: Taub P., Patel P., Buchman S., Cohen M. (eds) Ferraro's Fundamentals of Maxillofacial Surgery. Springer, New York, NY)

Table 1 Branches of the external carotid artery

Superior thyroid
Ascending pharyngeal
Lingual
Facial
Occipital
Posterior auricular
Internal maxillary
Superficial temporal

The internal maxillary and superficial temporal arteries are the terminal branches of the external carotid and are relatively small caliber vessels with higher flow creating the potential for brisk bleeding should any damage occur to them directly. The internal maxillary artery can be divided into three portions: a proximal ramal portion, a central muscular portion, and a distal sphenoid portion (Fig. 3). In total there are 17 branches which are involved in supplying blood to the midface, middle

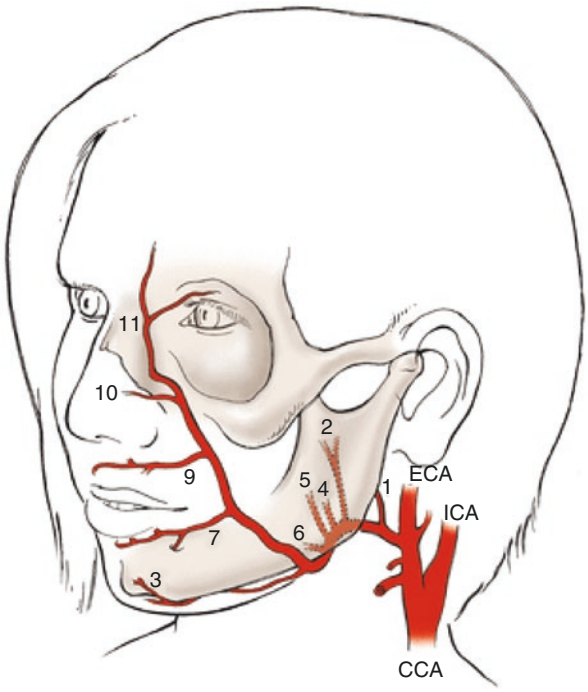

Fig. 2 The course of the facial artery is depicted, as well as the branching points that are involved in supplying the face. (*1*) Ascending palatine artery; (*2*) tonsillar artery; (*3*) submental artery; (*4*) inferior masseteric artery; (*5*) jugal trunk; (*6*) middle mental artery; (*7*) inferior labial artery; (*8*) anterior jugal artery (*not shown*); (*9*) superior labial artery; (*10*) lateral nasal artery; (*11*) angular artery (From: Harrigan M.R., Deveikis J.P. (2018) Essential Neurovascular Anatomy. In: Handbook of Cerebrovascular Disease and Neurointerventional Technique. Contemporary Medical Imaging. Humana Press, Cham)

cranium, temporal region, dental structures, and ocular structures. These branches are listed in Table 2.

The main trunk of the internal maxillary artery lies mainly within the infratemporal fossa, which also contains an abundance of other neurovascular structures. The infratemporal fossa is anteriorly bound by the posterior border of the maxilla. It is further bound posteriorly by the styloid process and the auricular tubercle of the temporal bone. It is bound medially by the lateral pterygoid plate, and laterally by the medial surface of the mandibular ramus. The superior roof of the area is defined by the greater wing of the sphenoid bone and the inferior aspect of the temporal bone [2]. Having a knowledge of the location and the contents of the infratemporal fossa is particularly relevant when working in the posterior maxilla or mandible, as it can be an area where infections spread, where objects are displaced or where other injuries propagate.

2.2 The Venous System

The venous system largely parallels the arterial system, with a few exceptions. One example is the retromandibular vein which runs posterior to the mandible and through the substance of the parotid gland. It is formed from the merging of the superficial temporal and maxillary veins. At the angle of the mandible, the retromandibular vein further divides into anterior and posterior divisions; the anterior

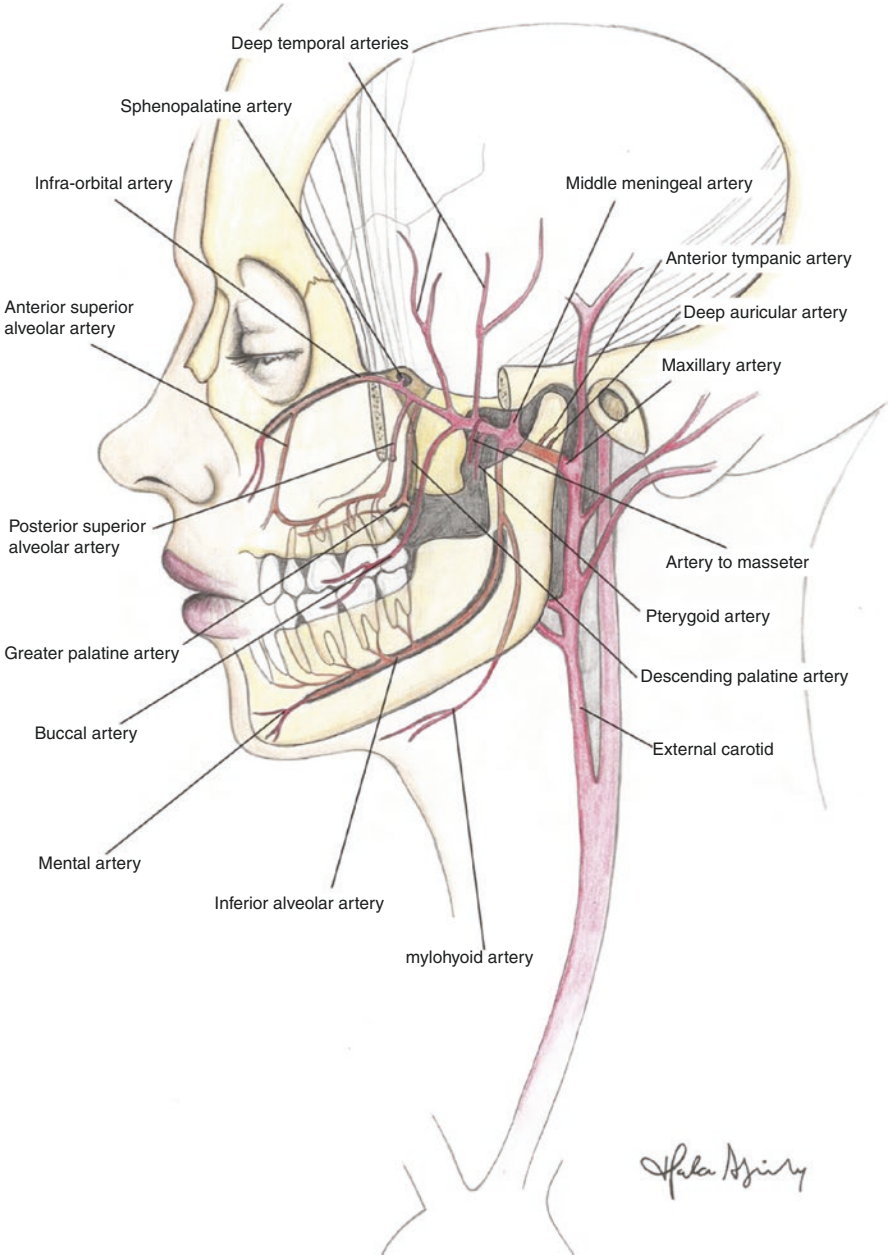

Fig. 3 The course of the internal maxillary artery and some of its main branches within the infratemporal fossa is shown (Taken from Hardiman R., Kujan O., Kochaji N. (2019) Normal Variation in the Anatomy, Biology, and Histology of the Maxillofacial Region. In: Farah C., Balasubramaniam R., McCullough M. (eds) Contemporary Oral Medicine. Springer, Cham)

Table 2 Branches of the internal maxillary artery

Proximal ramal portion	Deep auricular
	Anterior tympanic
	Middle meningeal
	Inferior alveolar
	Accessory meningeal
Central muscular portion	Masseteric
	Pterygoid
	Deep temporal
	Buccal
Distal sphenoid portion	Sphenopalatine
	Descending palatine
	Infraorbital
	Posterior superior alveolar
	Middle superior alveolar
	Pharyngeal
	Anterior superior alveolar
	Artery of the pterygoid canal

division unites with the facial vein to form the common facial vein which empties into the internal jugular vein, and the posterior division unites with the posterior auricular vein to form the external jugular vein.

The pterygoid plexus lies within the infratemporal fossa between the lateral pterygoid muscle and the temporalis muscle, as well as between the medial and lateral pterygoid muscles. This plexus is involved in the venous drainage of the surrounding veins and has communications with the cavernous sinus via the small emissary veins, which is significant as it provides a pathway into the middle cranial fossa [4]. This area is prone to development of hematomas when injured, such as during the administration of local anesthesia.

2.3 Blood Supply to the Mandible

The mandible receives its blood supply from the inferior alveolar branch of the internal maxillary artery, as well as from the surrounding periosteum. The primary blood supply to the mandible may shift with edentulous bone loss; in the fully dentate mandible, the primary blood supply moves in a centrifugal direction from the inferior alveolar artery compared to a centripetal direction from the periosteum in the edentulous mandible [5]. Therefore, in edentulous mandibles, periosteal elevation should be carried out judiciously to minimize the risk of vascular compromise.

Tagaya et al. [9] have also reported the presence of blood vessels that perforate the lingual cortex of the mandible which may be potential sources of bleeding and hematoma formation. The anatomical source of these perforating vessels has been described as originating from either the sublingual branch of the lingual artery or the submental branch of the facial artery. Tagaya et al. assessed CT images from 200 patients and found that lingual perforating vessels were present in the genial

tubercle region in 100% of patients: in 190/200 patients, perforating vessels were located superior to genial tubercles, in 99/200 patients vessels were located at the level of the genial tubercle, and in 114/200 patients vessels were located inferior to the genial tubercle. Additionally, they found that in 80% of patents there are also perforating vessels located lateral to the genial tubercles. Eighty eight percent of these lateral perforators were located on the lingual surface of the mandible adjacent to the mental foramen, and the remaining were found more anteriorly. The presence of these lingual perforating vessels should be considered both with direct placement of implants in the anterior mandible, and when dissecting lingual tissues [35]. Damage to the vessels in this area that is not noticed and controlled during surgery may present as hematoma formation in the postoperative period.

2.4 Blood Supply to the Maxilla

The vascular supply to the maxilla is more intricate and involves the anastomosis of multiple arteries arising from the external carotid artery. These branches include sphenopalatine artery, the descending palatine artery, the ascending palatine artery, and the ascending pharyngeal artery. The sphenopalatine artery is a direct branch of the internal maxillary artery and once it enters the nasal cavity through the sphenopalatine foramen, it further divides into the posterior lateral nasal artery and the posterior septal artery [2]. The descending palatine artery is also a direct branch of the internal maxillary artery which travels through the greater palatine canal before it divides posteriorly into lesser palatine artery to supply the soft palatal tissues, and anteriorly into the greater palatine artery to supply the hard palate. Of note, there are variations in the branching patterns and course of the greater palatine artery [6], which should be appreciated when placing implants in the maxillary molar region and when harvesting soft tissue from the palate. These branching patterns have been classified into four types, as depicted in Fig. 4.

The sphenopalatine arteries emerge onto the anterior hard palate lingual to the maxillary incisors through the nasopalatine (or incisive) foramen. The nasopalatine canal and foramen can vary in size, shape, and number of canals, which will be discussed further in the nerve injury section.

In addition to the vessels that directly supply the maxilla and mandible, adjacent vasculature structures can also be damaged. Some examples of more typically injured vessels include the lingual artery, inferior alveolar artery, buccal artery, greater palatine artery as well as the pterygoid venous plexus.

Hematomas generally occur secondary to bleeding from a site that was not recognized in the operative field, which may be less conspicuous when vasoconstrictor has been administered. Hematoma formation in the postoperative phase may be difficult to control and generally requires re-operation with the application of various hemostatic measures. Of particular concern are expansile hematomas from continued bleeding; these may enlarge and create a mass effect that can compress adjacent nerves and blood vessels, and more significantly lead to airway

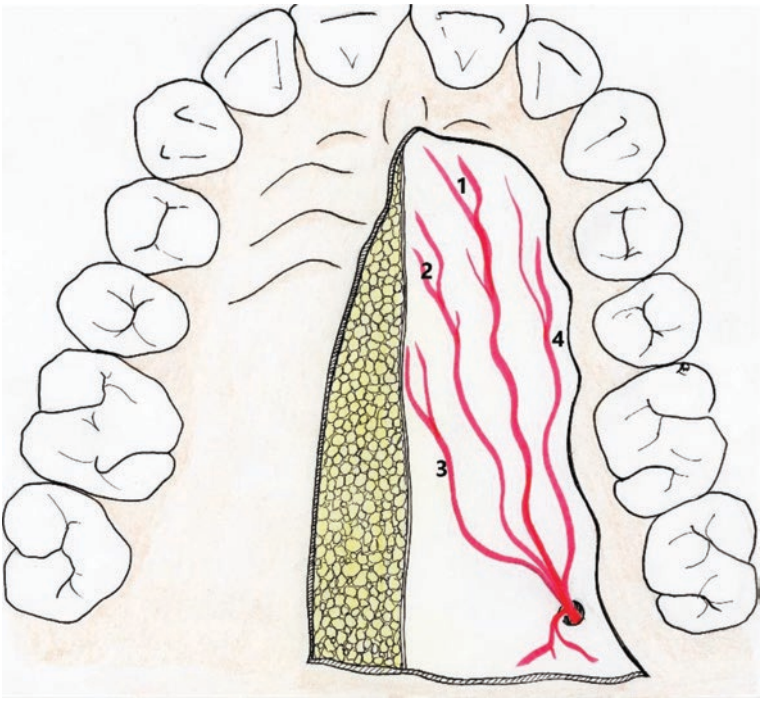

Fig. 4 There are up to four different branching variations of the greater palatine artery. The most common (41.7%) is a single vessel type 1; followed by a combination of type 1 and 3 (33.3%); followed by a combination of type 1 and 4 (16.7%) and less so as a combination of type 1 and 2 (8.7%)

compromise (Fig. 5) [8]. In the most severe cases, these require immediate surgical attention and the possible need for a tracheostomy [8]. During implant placement, vessels can be damaged during soft tissue dissection or from implants that perforate the bony cortex. As discussed previously, the floor of the mouth is rich in vasculature and has soft tissues that are relatively unbound and prone to expansion. Perforating the lingual cortex with the placement of dental implants has been implicated as the most common cause of hematomas of the floor of the mouth [7]. Large hematomas can compress the tongue to the roof of the mouth, and most importantly have the potential to obstruct the airway due to mass effect [8]. Placement of sutures in the floor of mouth should also be carried out with precision to avoid damage to the underlying structures.

Although complex, an understanding and respect for the vascular anatomy supplying the maxillomandibular region will allow the practitioner to minimize the incidence of any bleeding complications.

Fig. 5 Hematoma formation and epistaxis secondary to extraction of maxillary third molar with laceration of the PSA or pterygoid plexus managed with packing only

3 Neurologic Injuries

The most common cranial nerve implicated in dental implant related injury is the trigeminal nerve. The most commonly injured branches are the inferior alveolar nerve, the lingual nerve, and nasopalatine nerve due to their proximity to the mandible and maxilla. Although inferior alveolar nerve injury is more common, lingual nerve injuries tend to be more bothersome for patients and frequently result in legal action without proper informed consent [29]. Injury to these nerves can range from minor alterations in sensation to severely debilitating pain, as well as difficulties in swallowing and speech. A full discussion of trigeminal nerve injuries will take place in Chap. 9.

3.1 Overview of the Trigeminal Nerve

The trigeminal nerve is the largest cranial nerve (Fig. 6a) [10]. It contains mostly somatic afferent fibers with a smaller proportion of special visceral efferent fibers. It is responsible for sensation to the facial region, as well as motor control to the

muscles of mastication. The trigeminal nerve originates within the brainstem. The larger sensory nuclei are distributed along the brainstem and extend downward into the spinal cord. The sensory root (the major part of the nerve) forms the bulk of the fibers while the motor root (minor part) is formed by fibers from the small motor nucleus of the pons. The trigeminal nerve divides into its three main divisions at the trigeminal ganglion located at Meckel's cave within the middle cranial fossa. The three main divisions are the *ophthalmic (first division)*, *maxillary (second division)*, and *mandibular (third division)* (Fig. 6b). These nerves exit the cranium via different bony foramina: the ophthalmic division travels through the superior orbital fissure, the maxillary division exits via foramen Rotundum, and the mandibular division travels though foramen ovale [10].

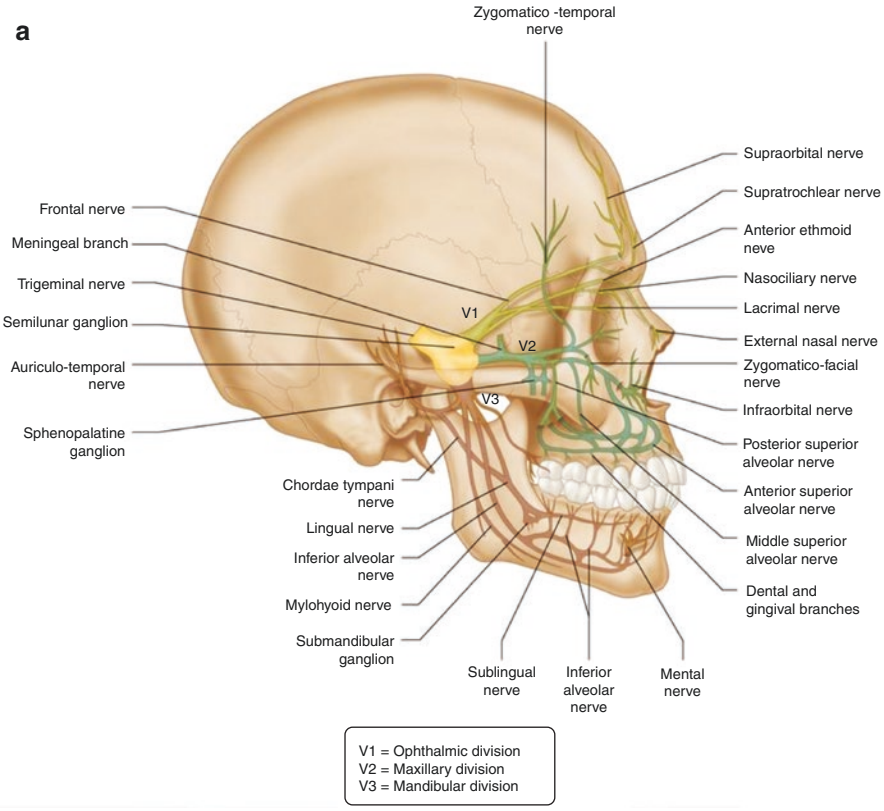

Fig. 6 The distribution of the ophthalmic, maxillary, and mandibular divisions of the trigeminal nerve. (**a**) Wexler A.M. (2015) Anatomy of the Head and Neck. In: Taub P., Patel P., Buchman S., Cohen M. (eds) Ferraro's Fundamentals of Maxillofacial Surgery. Springer, New York, NY. (**b**) Taken from Merritt G., Walji A.H., Tsui B.C.H. (2016) Clinical Anatomy of the Head and Neck. In: Tsui B., Suresh S. (eds) Pediatric Atlas of Ultrasound- and Nerve Stimulation-Guided Regional Anesthesia. Springer, New York, NY

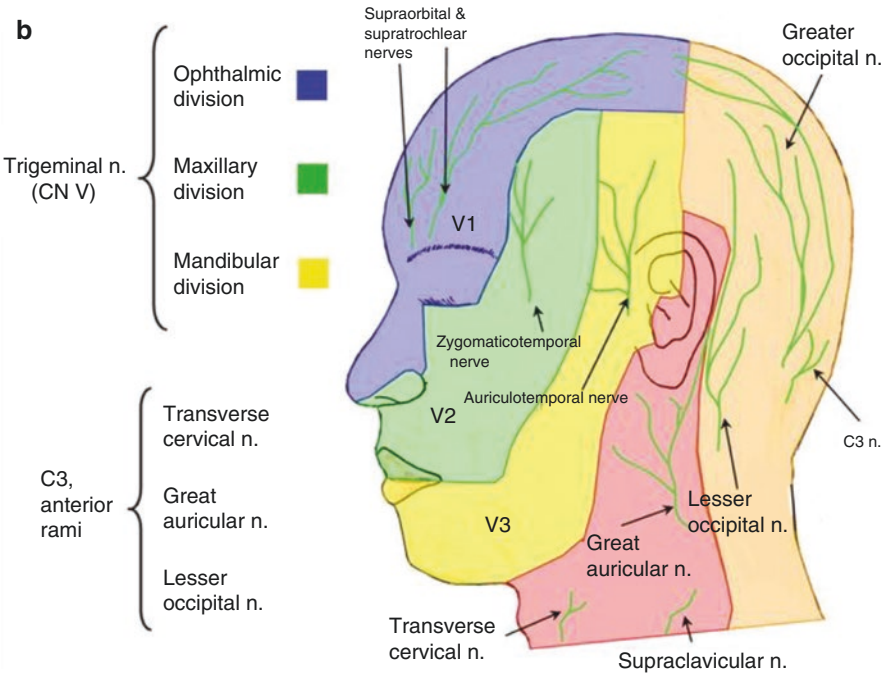

Fig. 6 (continued)

The mandibular division gives off the meningeal branch, and motor branches to the tensor tympani muscle, medial pterygoid muscle, and tensor veli palatini muscle before splitting into the anterior and posterior divisions. The anterior division is generally regarded as a motor division for the muscles of mastication; however, it does give off the buccal branch which supplies sensation to the buccal mucosa and mandibular buccal gingiva [2].

The posterior division is generally the source of most implant related complications and will be the focus of this section. The branches of the posterior root of the mandibular division include the auriculotemporal nerve, the lingual nerve, and the inferior alveolar nerve. The inferior alveolar nerve branches further to form the mylohyoid nerve, which also has motor function to the mylohyoid muscle and the anterior belly of the digastric muscle.

3.2 The Lingual Nerve

The lingual nerve supplies sensation to the mucous membranes of the lingual mandibular gingiva, floor of the mouth, and the anterior two-thirds of the tongue [11]. In addition, the chorda tympani branch of the facial nerve joins with the lingual nerve approximately one to two centimeters below the bifurcation of the lingual and

inferior alveolar nerves near the inferior aspect of the lateral pterygoid muscle. The chorda tympani is involved in supplying special sensory taste to the fungiform papillae on the anterior two-thirds of the tongue [11].

In the mandibular third molar region, the lingual nerve is particularly amenable to damage, especially when the nerve is not appropriately protected during the elevation of lingual flaps or with careless osteotomy placement. In the third molar region, the lingual nerve has been reported to be at the level of the alveolar crest or higher 10–17.6% of the time [12]. Furthermore in Kiesselbach and Chamberlain's cadaveric study it was demonstrated that the lingual nerve contacts the lingual plate in the third molar area in 62% of cases [13]. Therefore, caution should be exercised when managing lingual tissue in the posterior mandibular region, or when performing osteotomies in close proximity to the lingual cortex.

Anteriorly, the lingual nerve travels in a more medial direction and crosses over the submandibular duct. This generally occurs in the interproximal region between the mandibular first and second molars, before it gives off multiple branches to supply the tongue [12]. The complex and intricate anatomy and the structures in the lateral pharyngeal space are illustrated in Fig. 7. Some examples of mechanisms leading to lingual nerve damage include: administration of local anesthesia, thermal

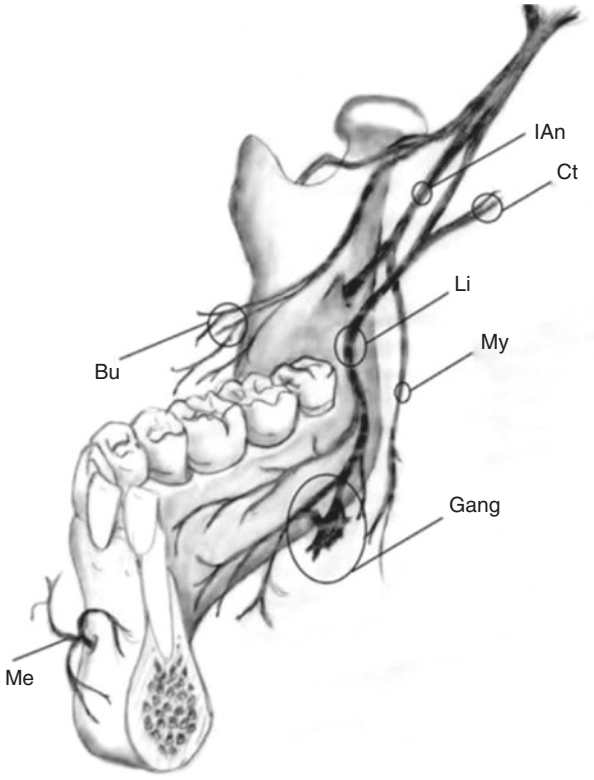

Fig. 7 *Ct* chorda tympani, *IAn* inferior alveolar nerve, *Li* lingual nerve, *My* n' to mylohyoid, *Me* mental nerve, *Gang* submandibular ganglion

injury (from cautery, lasers, or rotary burns), direct trauma from sutures, direct damage from a breach in the lingual cortex, and from improper soft tissue manipulation and handling (particularly in the region of the posterior mandibular dentition) [11]. Damage to the lingual nerve can result in altered salivary secretion on the affected side, slurred speech, loss of taste, and altered sensation on the anterior two-thirds of the ipsilateral tongue [11]. Lingual nerve injuries tend to be particularly debilitating for patient quality of life relative to injuries of other surrounding sensory nerves and they tend to be difficult to treat, so knowledge and respect of lingual nerve anatomy is crucial.

3.3 Parasympathetic Innervation

The pre-ganglionic nerve fibers that supply the submandibular ganglion also travel with the lingual nerve and the chorda tympani. The submandibular ganglia are one of the four groups of parasympathetic ganglia supplying the head and neck. The pre-ganglionic fibers to the submandibular ganglia originate from the superior salivatory nucleus of the pons before they arrive at the submandibular ganglion near the posterior border of the mylohyoid muscle, and on the hyoglossus muscle. From here, the parasympathetic fibers innervate the submandibular and sublingual glands, allowing for salivation.

The other parasympathetic ganglia in the head are the ciliary, otic, and pterygopalatine. The presynaptic fibers originate from the oculomotor, facial, and glossopharyngeal nerves; the postsynaptic fibers travel to the ciliary muscle, lacrimal gland, and parotid gland, respectively.

3.4 The Inferior Alveolar Nerve

The inferior alveolar nerve enters the mandibular canal at the mandibular foramen and travels within mandible to supply sensation to the mandibular molars and mandibular second premolar. More anteriorly the nerve branches into the incisive nerve to supply the remaining mandibular teeth, as well as the mental nerve which exits the mandible through the mental foramen and supplies sensory innervation to the lower lip, chin, and gingiva of the anterior mandibular dentition. Upon exiting the mental foramen, the nerve splits into three terminal branches to supply these areas.

The inferior alveolar nerve travels within the inferior alveolar canal with the inferior alveolar artery and vein, collectively referred to as the neurovascular bundle. The canal can be one of three shapes: round/oval, tear-drop, or dumb-bell shaped [27]. The approximate diameter is generally in the range of 2.3–2.7 mm [28], though the exact shape and course of the canal can be confirmed with three-dimensional imaging prior to implant placement. Within the canal, the vein tends to run superior to the artery and nerve in the 12 o'clock position, the artery tends to run

in the inferolingual aspect of the canal, and the nerve is generally in the inferobuccal position [14].

As a general rule in anatomy, variation from typical patterns exists. One example of this is the bifurcated or trifurcated inferior alveolar nerve [15]. Chavez et al. report that the inferior alveolar nerve is formed from the fusion of three separate components, so a lack of fusion has the potential to form three separate inferior alveolar canals or any intermediate permutation [15, 16].

The mental foramen is generally in the region of the second mandibular premolar, or in the interproximal region between the first and second premolars. Even with visualization of the mental foramen, the operator must be aware of the possible presence of an anterior loop of the mental branch. The incidence and average size of the mental loop is not clear; however, when placing implants in the region of the mental foramen, this area should be appropriately evaluated for each individual with the appropriate imaging [36]. When manipulating tissues in the mental region, care should be taken to protect the mental nerve to minimize the risk of neurosensory deficits.

The inferior alveolar nerve can be damaged through direct trauma from dental implants impinging on the bony canal, as well as from trauma in the mental region. Other possible etiologies of inferior alveolar damage include local anesthetic administration, and damage when harvesting bone from the mandibular ramus or symphysis.

When harvesting bone from the ramus, direct nerve injury can occur due to the proximity of the inferior alveolar nerve to the buccal cortex. Clinical and radiographic studies demonstrate that the cortical thickness in the region of mandibular second molar is 4.9 mm on average, and the average distance from the superior cortical surface is 17.4 mm, which also depends on age, sex, and race [30]. In general, it is recommended that a penetrance of greater than 2.75 mm into the cortical bone when harvesting ramal bone may increase the risk of inferior alveolar nerve injury [20]. Further caution should be exercised in prognathic mandibles as they tend to have thinner overall buccal-lingual dimensions and thinner cortices. Yamamoto also cited that any osteotomy within 0.8 mm of the buccal cortex may result in higher incidence of neurosensory deficit [19]. Ultimately, it is important to evaluate the position of the inferior alveolar nerve canal with appropriate imaging and having a general idea of where the patient's nerve lies with respect to their individual anatomy when performing osteotomies in the area.

Neurologic deficits from symphyseal injuries can range from a persistent dull wooden sensation in the anterior teeth to complete anesthesia or dysesthesia of the mental region. While not a neurologic injury, the risk of symphyseal fracture also needs to be considered when harvesting bone from the region. The incidence of complications and neurosensory deficits is also generally higher when harvesting symphyseal bone compared to ramal bone, which is partly attributable to the greater degree of cortical bone and less relative cancellous marrow [17, 18].

3.5 The Nasopalatine Nerve

In the anterior maxilla, the nasopalatine nerve travels through the nasopalatine (incisive) canal to supply sensation to the anterior aspect of the hard palate. The anatomy of the nasopalatine canal is variable in terms of shape and size, though the average width is 6 mm. Wider variants will reduce the amount of bone available for implant placement. Different variations in nasopalatine anatomy have been described, and it has been classified into three types: type I is a single canal, type II is two parallel canals, and type III includes variations of the "Y-shaped" canal. The "Y-shaped" canal includes a canal with a single oral opening (incisive foramen) and two or more nasal openings (foramina of Stenson) [26, 31]. With current imaging modalities such as CBCT or CT, practitioners should be able to identify and plan implant placement appropriate to avoid this anatomic structure.

In the case of the severely atrophic maxilla with otherwise insufficient volume of bone for implant placement, placement of an implant into the site of the nasopalatine foramen has been described [32]. When utilizing this technique, the practitioner must be aware of the nasopalatine neurovascular bundle, and that the risk of developing bothersome neurosensory deficits exists. However, these deficits fortunately are generally limited to transient numbness of the anterior one-third of the palate.

4 Osseous and Dental Injuries

Injuries of maxillary and mandibular bone are known complications of implant placement, however with the increased demand for harvesting intraoral bone, injuries have the possibility of further extending into the zygoma and the infratemporal fossa. These injuries may include fractures, displaced bony spicules, and bony defects. To minimize the incidence of osseous injuries, a knowledge of bone volume, quality, and shape for each individual patient is required.

The volume, shape, and quality of bone can be assessed with the three-dimensional imaging. When placing implants, the shape of the bone and the presence of concavities in both the mandible and maxilla needs to be considered for each individual patient. A common example is that of the submandibular and sublingual fossae on the medial aspect of the mandible, which may be more pronounced in certain patients. These areas can be fully visualized with three-dimensional imaging to aid in treatment planning. In the event that the cortex is perforated there is increased risk of damage to the surrounding nerves and vasculature, as well as increased risk of infection. As discussed previously, structures that may be damaged on the lingual aspect of the mandible includes the lingual nerve, as well as lingual blood vessels.

As mentioned above, the practitioner should be aware of the quality of bone. Bone quality varies based on the location in the mouth and can be further affected by medical comorbidities. Components of the patient's medical history

may be helpful and determining which patients may have weaker than normal osseous architecture, such as patients with osteoporosis or prior radiation. This is discussed further in chapter "Medical Complications in Dental Implantology".

4.1 The Maxillary Sinus

The maxillary sinus *or antrum* is a bilateral airspace that is lined with a bilaminar membrane known as the Schneiderian membrane. The internal aspect of the membrane is pseudostratified ciliated columnar epithelium, and the more external aspect of the membrane is composed of periosteum. The antrum generally extends from approximately the region of the first maxillary premolar posteriorly to the region of the third molars [21]. However, the size of the antrum can increase through the process of sinus pneumatization, particularly in edentulous regions that may be the site of future implant placement. The operator needs to be cognizant of proximity of the sinus to avoid complications such as the displacement of foreign bodies and root fragments, and to avoid persistent oroantral communications.

The posterior superior alveolar and infraorbital arteries also have branches in the lateral maxillary sinus wall. Kqiku et al. demonstrated that an intraosseous anastomosis between these vessels was generally present, as well as an adjacent extraosseous anastomosis 90% of the time. The average distances in the dentate maxilla from the alveolar ridge to the area of the intraosseous anastomosis were 17.7 mm in the second molar region, 14.5 mm in the first molar region, and 14.7 mm in the second premolar position [22]. This is an important consideration when planning for sinus augmentation procedures with respect to bleeding.

4.2 Mandible Fractures

One of the more severe complications that can occur secondary to dental implant placement is mandible fractures. Fortunately, this complication is rare and is almost always preventable with appropriate preoperative planning. During the planning phase, it is important to recognize a weak osseous structure due to either lack of volume or insufficient bone quality. A common scenario where mandible fractures occur is in atrophic mandibles (Fig. 8). Placing dental implants into an already

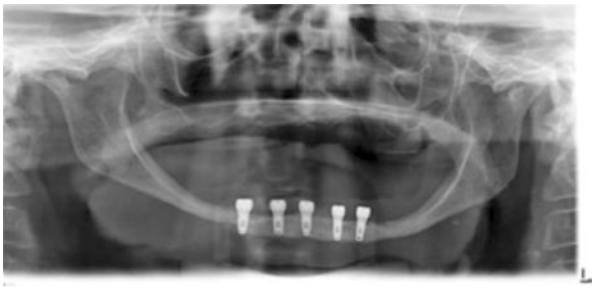

Fig. 8 Implants placed in an atrophic mandible placing it at risk for fracture

weakened osseous structure greatly increases the probability of fracture. When placing implants in mandibles with reduced bony volume, one should attempt to avoid perforating multiple cortices of bone as this will significantly reduce osseous strength [23]. Commonly, these fractures occur in the postoperative period rather than intraoperatively. The patient may report that they heard a "break," or "crack" which may or may not be associated with pain. The repair of mandible fractures in these situations is generally challenging and requires significant surgery with the possible need for extraoral bone grafting. The "best treatment for implant related mandible fracture is prevention" [23].

Persistent, chronic, or obstinate periimplantitis can also weaken the osseous structure and increase the risk of fracture. Additionally, infection from a localized implant or fracture has the potential to spread to adjacent fascial spaces [24]. This will be discussed further in the next section.

5 Case: "Infected Implants"

A 65-year-old woman was referred by her family doctor for management of "infected implants" performed out of country. The orthopantomogram in Fig. 9a demonstrates the poor status of implants and affected bone in the mandible and maxilla. The patient had complaints of continued purulent drainage from the implant sites, as well as generalized pain in the region and the inability to wear her dentures. A computed tomogram was obtained which demonstrated a small fracture in the inferior cortex of the mandible which added further challenges in treating the condition (Fig. 9b).

Clinical exam demonstrated purulent drainage from the implant sites, limited mouth opening, fetid odor, and mobile implants. Closer inspection also demonstrated an implant in the left maxilla to have penetrated the inferior turbinate which by its direction appeared to be an intentional placement. During interviews of the patient, it was determined that the original practitioner attempted an "all-on-four" method to get her teeth in a day. Unfortunately, no salvage procedures were possible, and the decision was made to remove the implants and debride the infected area and start from the beginning. A postoperative orthopantomogram of the residual defect is shown in Fig. 9c. This case demonstrates the unfortunate outcome of poor planning. Images of her preoperatively indicated good quality and quantity of bone but the practitioner was unable to scrutinize these benefits and it can be assumed that poor planning (or experience) is the cause. Both deficiencies are direct reflections on the lack of knowledge of anatomy.

5.1 Dental Injuries

Dental injuries are often due to either implant osteotomy impingement on an adjacent tooth (Fig. 10) or from direct injury to teeth from careless instrumentation (Fig. 11) [34]. With proper radiographic, clinical examination and preparation the

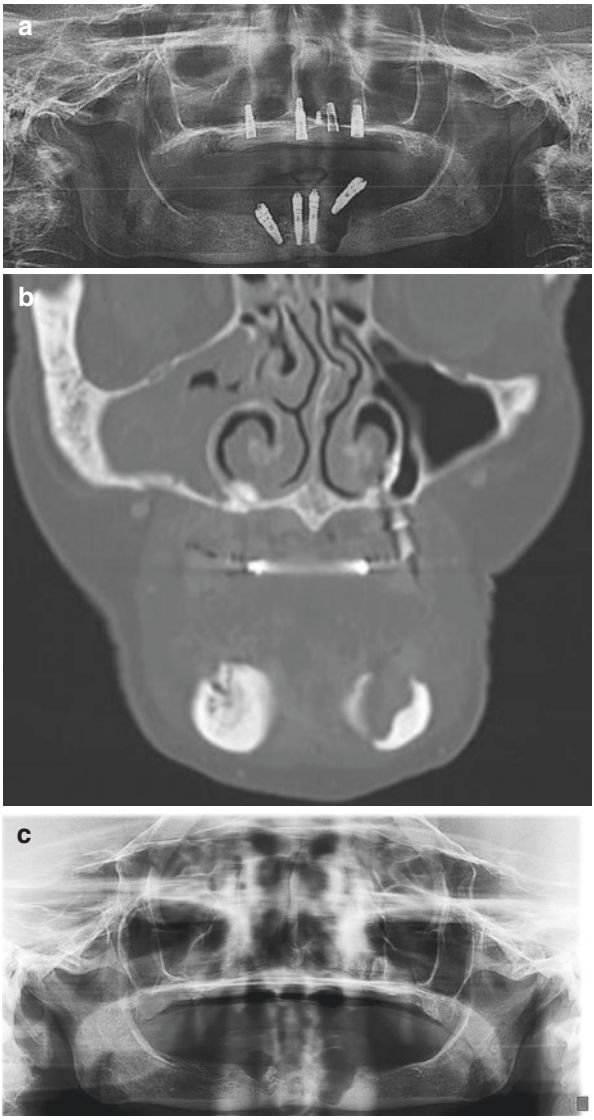

Fig. 9 (**a**) Implants placed with insufficient bony support. Bone loss around the implant in the left anterior mandible demonstrates a lack of bone at the inferior mandibular cortex placing the mandible at risk for fracture. (**b**) A coronal cut of the CT demonstrates a small fracture at the severely thinned mandibular cortex. Perforation into the right maxillary sinus with concurrent sinusitis is suspected based on the opacification observed in the image. (**c**) The residual defect after implant removal and debridement

risk of dental injuries should be minimized. Thorough knowledge of dental anatomy, root morphology, presence of dilacerations, bulbous root shapes, root inclinations, and tooth position should be intuitive for dental implant practitioners in order to minimize frivolous damage.

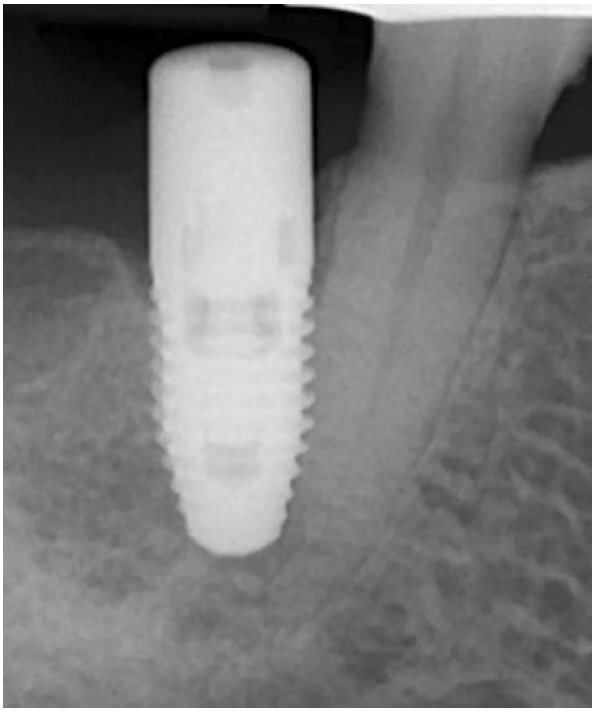

Fig. 10 Dental implant placement impinging on the PDL space of the adjacent tooth

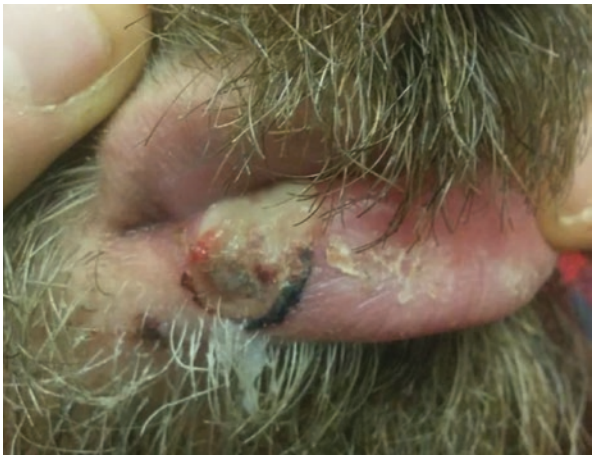

Fig. 11 A healing wound secondary to a burn caused from a rotary instrument

5.2 Soft tissue Injuries

Generalized soft tissue injuries can occur in the process of placing dental implants, as they can occur with any other maxillofacial procedure. Examples of soft tissue injuries include: tears, lacerations, perforations, abrasions, crush injuries, burns, and contusions. Most of these injuries are secondary to improper use of instruments, and

improper surgical technique. These injuries can be caused directly from rotary instruments, scalpel blades, electrocautery, clamps, chemical agents, and even residual gauze or packing material.

6 Involvement of Fascial Spaces

In healthy circumstances, there is a strong adherence between the various tissue planes. However, potential spaces exist between tissue planes when interplane adhesions are disturbed. This may be secondary to the spread of infections, air (emphysema), or blood (hematoma). All these situations are possible when placing dental implants; therefore, the practitioner should be aware of adjacent fascial spaces and the routes of potential spread (Fig. 12).

The primary fascial spaces are defined as the spaces involved in direct spread from the dentoalveolar complex. When more distant spaces become subsequently involved, they are referred to as secondary spaces. The primary maxillary spaces include the vestibular space, the palatal space, the canine space, the buccal space, and rarely the infratemporal space. The primary mandibular spaces include the vestibular space, the buccal space, the submental space, the sublingual space, and the submandibular space. A full description of these spaces is provided in Table 3. The route of spread is generally dictated by proximity and the path of least resistance. The insertion of muscles also impacts which spaces become primarily involved. For example, if an infection originates superior to the attachment of the

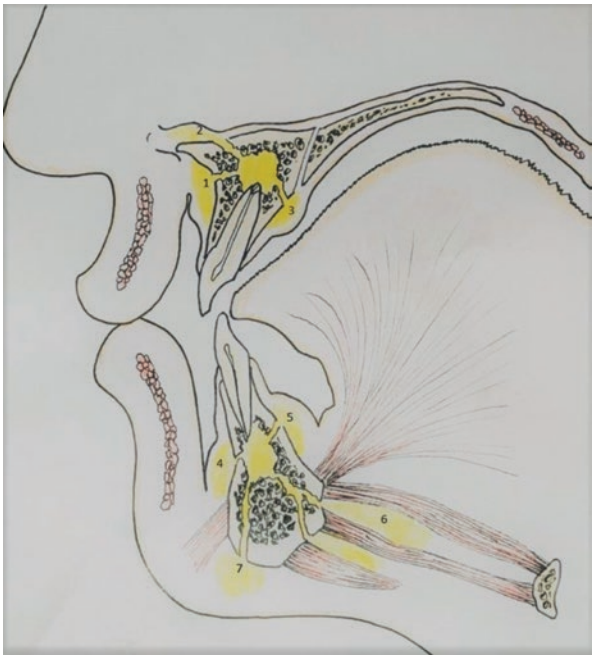

Fig. 12 Sagittal section through the oral cavity to show possible routes of spread for infections from the anterior teeth

Table 3 Boundaries of the fascial spaces

Canine	Between the canine fossa of the maxilla, levator labii superioris, and the levator anguli oris muscles
Buccal	Medial: Buccinator and buccopharyngeal fascia Lateral: Skin of the cheek Anterior: Labial muscles Posterior: Pterygomandibular raphe Superior: Zygomatic arch Inferior: Inferior border of the mandible
Sublingual	Superior: Floor of the mouth mucosa Inferior: Mylohyoid muscle Anterior/lateral: Mandible Medial: Genioglossus and geniohyoid muscles
Submental	Anterior/Superior: Inferior border of anterior mandible and the mentalis muscle Posterior/Superior: Mylohyoid muscle Lateral: Anterior bellies of the digastric muscles Inferior: Hyoid bone
Submandibular	Superior: Mylohyoid muscle Inferior: Anterior and posterior bellies of the digastric muscles Medial: Mylohyoid, hyoglossus, and styloglossus muscles Lateral: Skin, platysma, superficial layer of the deep cervical fascia, mandible
Submasseteric	Superior: Zygomatic arch Inferior: Inferior border of mandible Medial: Ascending ramus Lateral: Masseter muscle
Pterygomandibular	Superior: Lateral pterygoid muscle Anterior: Pterygomandibular raphe Medial: Medial pterygoid muscle Lateral: Ascending ramus Posterior: Parotid gland
Superficial temporal	Between the temporalis muscle medially and the deep temporal fascia laterally
Deep temporal (Infratemporal)	Between the temporalis muscle laterally and the temporal bone/greater wing of the sphenoid bone medially
Lateral pharyngeal	Superior: Base of skull Inferior: Hyoid bone Anterior: Pterygomandibular raphe Posterior: Parotid gland Medial: Superior pharyngeal constrictor muscle Lateral: Medial pterygoid muscle *Note: The space is divided into anterior and posterior compartments by the aponeurosis of Zuckerkandl and Testut (the posterior compartment contains the carotid sheath)*
Retropharyngeal	Superior: Base of skull Inferior: C7 or T1 Anterior: Posterior pharyngeal wall Posterior: Alar layer of the pre-vertebral fascia
Prevertebral	Superior: Base of skull Inferior: Upper mediastinum Anterior: Alar layer of the pre-vertebral fascia Posterior: Pre-vertebral fascia

mylohyoid muscle, the sublingual space will first become involved. Conversely, if the infection originates inferior to the mylohyoid attachment, the submandibular space will initially become involved without involvement of the sublingual space.

The severity of the complication worsens as secondary fascial spaces become involved. The secondary spaces of the head and neck include the submasseteric space, the pterygomandibular space, the superficial and deep temporal spaces, the lateral pharyngeal space, the retropharyngeal space, and the prevertebral space. The boundaries of these spaces are listed in Table 3. Involvement of fascial spaces surrounding the muscles of mastication can present with trismus due to inflammation of the associated muscles, as well as mass effects.

The most concerning and emergent complication associated with fascial spaces is when a mass effect impedes the airway. Furthermore, when the prevertebral and retropharyngeal spaces are involved, they can act as a conduit to the mediastinum or into the cranial fossa. Fluid or air collections in these spaces often require immediate surgical attention.

While not directly related to implant placement, the use of high-speed air-driven handpieces or air-water syringes has the potential to cause subcutaneous air emphysema. These instruments should be avoided in bony cavities or underneath soft tissue flaps. Interestingly, subcutaneous emphysema can also occur secondary to a simple cough during or after surgery, or from prolonged surgical procedures with exposure of bony cavities. Any continued force of air can lead to inflation of facial spaces. As with infections, air can pass through primary fascial spaces and into secondary fascial spaces. While most cases of subcutaneous air emphysema may be self-limiting, rarely they can also be fatal. The potential exists for airway embarrassment, life-threatening air-embolism, as well as the introduction of oral flora into the mediastinum causing mediastinitis. The introduction of the oral flora into the mediastinum requires immediate action and admission with aggressive medical and possibly surgical management [25].

6.1 Displaced (Lost) Material

Displaced material is not uncommon in dentistry, especially in awake patients when limited sedative options are available. The possibility of displacement of foreign materials (such as implant components—Fig. 13a) into fascial spaces, the sinus or into the oropharynx exists. Small implant components require the practitioner to be cognizant of the possibility of displacement into surrounding regions. If a foreign object enters the oropharynx, they can be further dislodged into the digestive tract or aspirated into the respiratory system. Most often if aspirated the objects would be found in the right mainstem bronchus [33]. The treatment of this is bronchoscopic examination and retrieval. If ingested, the material most often passes but abdominal films should be taken to monitor the passage (Fig. 13b). The best method of prevention for these is placement of a throat pack or shield and the use of ligation, floss or suture floss if a small instrument is being used.

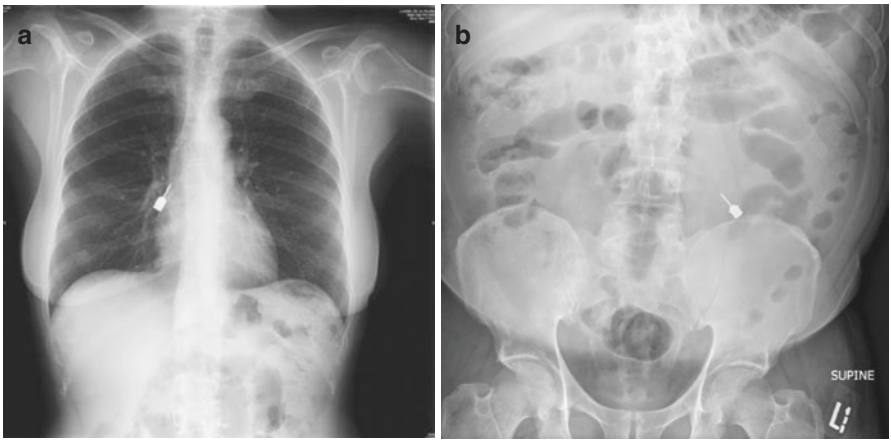

Fig. 13 (**a**) A chest X-ray that demonstrates an implant driver that was aspirated into the right main stem bronchus (Taken from Pingarrón Martín, L., Morán Soto, M.J., Sánchez Burgos, R. *et al.* Bronchial impaction of an implant screwdriver after accidental aspiration: report of a case and revision of the literature. *Oral Maxillofac Surg* 14, 43–47 (2010). (**b**) An abdominal radiograph was taken after an implant driver was displaced into the digestive tract

7 Case: Displaced Implant During Stage I Surgery

The placement of an implant at the site of the left maxillary first molar is being performed. After an uneventful osteotomy through the alveolus, a 10 mm implant is inserted to the proper depth. While torqueing the implant into the place, the patient flinches and the implant is lost from site. Where are the possible anatomic locations that the implant can be located?

7.1 Possible Areas of Displacement

- Oral cavity.
- Extraorally.
- Respiratory tract.
- Digestive tract.
- Maxillary sinus.
- Vestibular space or buccal space.
- Infratemporal space.

7.2 Approach

The first location to look is the oral cavity. If a throat pack was placed, it should be removed, and the oral cavity can be thoroughly inspected (without performing a

blind sweep). If the implant is not visualized in the oral cavity, displacement of the implant extraorally can be considered.

Symptoms such as coughing, stridor, and chest discomfort are suggestive of aspiration. If dislodgment into the respiratory or digestive system, a chest X-ray and/or abdominal X-ray should be obtained for verification.

The surgical site should be further explored. The implant osteotomy site should be explored for any perforations into the maxillary sinus. The surrounding soft tissues can also be examined for any possible communications with the surrounding fascial spaces, such as the vestibular or infratemporal spaces. Localization can be supplemented with a CBCT or two plain film radiographs that allow for three-dimensional visualization. If the implant is found to be in the sinus, vestibular space, or in the infratemporal fossa, careful manipulation is required to avoid further dislodging the implant. In many cases, the recommendation would be to further inspect these areas under deep sedation or general anesthesia. The most difficult area to navigate through is the infratemporal fossa. It is a very challenging area to dissect and blind reach may produce disastrous outcomes due to the abundance of neurovascular structures in the region as previously described.

8 Conclusions

A thorough understanding and respect of anatomy is crucial to minimizing and treating complications associated with dental implant placement. With a knowledge of anatomy, proper preoperative planning, and appropriate surgical technique, many of these complications can be avoided.

The generalization of "implant complications" cannot be fully detailed without intimate knowledge of maxillofacial anatomy. Understanding the vascularity, complex neurology, and fragile fascial spaces produces knowledgeable practitioner able to manage these complications. However, with knowledge should come the respect for tissues and surgical skills that enable us to maintain the best level of care with minimal morbidity.

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Aesthetic Dental Implant Complications

Hossein Behnia, Navid Sharifzadeh, and Parsa Behnia

1 Background

The word "aesthetic"! If we go back to the origin of this word, it came from the Greek word aisthēta which means "perceptible things." In the old days, whatever was seen or noticed was described as "beautiful"—a term which is not used in this way today. Beauty standards have constantly changed as time has lapsed and the society has offered an innovative "look" or created new "trend."

If we want to extrapolate it to dentistry, especially implant dentistry, the same path of development should be followed.

The early stages, during which implant was only regarded as a functional anchorage for dentures, and now that a miniscule black triangle in the papillae of the anterior maxillary teeth is viewed as a serious problem; this shed light on the evolution of implant dentistry.

In the first 25 years, modern implant dentistry was based on the concept of osseointegration [1, 2], and implant placement was primarily performed in healed sites of fully edentulous patients [3, 4]. Most of the patients had been edentulous for years and the use of dental implants was aimed at improving masticatory function and quality of life [5].

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In the 1980s, dental implants were cautiously used for partially edentulous patients, and the first published reports yielded encouraging results [6–8]. Since then, the number of partially edentulous patients using implants has considerably increased and today, these indications predominate in daily practice, in particular single-tooth replacement [9, 10].

In the case of single-tooth replacement, the old concept was to postpone the treatment for six months after the extraction. This approach of implant placement into healed sites has been totally abandoned now. The comprehensive understanding of post-extraction dimensional ridge alterations [11, 12] demonstrates that this approach frequently complicates therapy, and a post-extraction healing period of at least six months is necessary prior to implant placement. The interval is not appealing to patients in the modern world.

Evaluating the clinical and aesthetic outcomes of implants placed in post-extraction sites in subsequent years to 2008, the number of clinical studies increased significantly as analyzed in a second systematic review by Chen and Buser [13]. The literature search for the fourth ITI Consensus Conference 2008 in Stuttgart, Germany, resulted in 91 studies, which met the criteria of including at least ten implants and carrying out at least 12 months of follow-up work [5].

The authors concluded that bone augmentation procedures are effective in promoting bone fill and defect resolution at implants in post-extraction sites, and that these procedures are more successful for immediate and early implant placement when compared with late implant placement. The majority of studies reported survival rates above 95%.

As documented in the literature [14–18] implant is a suitable alternative to a missing tooth. To patients, however, the success of implant therapy is mediated not only by the long-term function of the implant, but also by both the initial aesthetic outcome and its stability over time [18].

Careful planning and knowledge of the natural dentition's characteristics are necessary for the rehabilitation of the aesthetic zone. Clinical and radiographic examinations, study of models through diagnostic waxing, and cooperation with other specialists may be the key to a high aesthetic and functional success [19]. The success of a single restoration in the aesthetic zone depends mainly on the harmonious integration of the restoration into the patient's overall appearance, especially the peri-implant soft tissue.

Both *subjective* (patients' ratings) and *objective* (aesthetic scores and indices) assessments of implant aesthetics are subject to growing interests [20].

On the *subjective* aspect, the aesthetic zone definition will be demarcated mostly by the patient. An aesthetic area can be defined as any area to be restored that is visible in the patient's full smile or the area that can be seen and/or noticed by the patient.

In the modern world, the expectation from a dental implant has been completely transformed from what has been anticipated before. The more implants are placed in the aesthetic zone, the more complications associated with this treatment protocol are developed. So, the need for documentation of aesthetic complications and definition of risk factors arises.

On the *objective* aspect, different clinical criteria and scores have been proposed. The studies reported detailed results about the aesthetic outcomes, which were also favored by the development of aesthetic indices such as the Pink Aesthetic Score (PES) [21] and White Aesthetic Score (WES) [22].

The Pink Aesthetic Score by Furhauser et al. [21] includes seven criteria exclusively to assess peri-implant soft tissues: mesial papilla, distal papilla, midfacial level, midfacial contour, alveolar process deficiency, soft tissue color, and soft tissue texture.

On the contrary, the White Aesthetic Score by Belser et al. [22] evaluates the aesthetic outcome of implant restoration by analyzing only the coronal restoration in terms of tooth form, tooth volume, tooth color (with hue and value), tooth texture, and translucency.

Although the pivotal point is what would be the major element that secures the predictability of the implant aesthetic success, it depends on the tissue loss present at the initiation of treatment. The greater the amount of bone and soft tissue loss, the more challenging it becomes to yield an ideal aesthetic result [23].

Apart from that, there is an enormous distinction between single and multiple missing teeth in the aesthetic zone.

Single-tooth implants have a high degree of predictability as the adjacent teeth can provide the morphological substructure that is prerequisite to restore natural gingival and papillary architecture. Therefore, the level of the bone attachment on the adjacent teeth will predict the presence or absence of the soft tissue in the interproximal area.

Replacement of multiple missing teeth in the aesthetic zone is challenging particularly when there is a three-dimensional deficiency in the architecture of the existing bone and soft tissue [23]. Under such circumstances, the bony housing would require augmentation to provide a configuration that permits placement of implants in optimal positions which in turn would result in pleasing aesthetics.

To obtain a desired outcome, diagnosis and appropriate treatment planning are critical. Although the implant design, surface characteristics or type of abutment are very important, they will not guarantee an aesthetic result. The time a clinician spends reaching out to an optimum treatment plan to fulfill the function and aesthetic feature of an individual is actually crucial.

Whenever we judge an implant a success, we have to apprehend that we cannot describe it as successful on cases the implant has only been integrated. Implants placed in poor restorative positions result in unaesthetic restorations that provide the clinician and also the patient with little satisfaction.

The clinical cases in this chapter demonstrate the complexity of implant use in aesthetic zones and the importance of proper treatment planning prior to implant placement.

A solid treatment plan should address the following major factors:

- Hard tissue at the site of implant (quality and quantity).
- Soft tissue at the site of implant (quality and quantity).
- Implant position.

- Single versus multiple implants.
- Implant diameter.
- Level of the bony attachment on the adjacent teeth.
- Timing; immediate, early, late.
- Impact of immediate provisionalization.
- Patient selection and smile line.
- Clinical skill and experience.
- Corrective surgical interventions.

The abovementioned factors, if taken into account accurately, will lead to a restoration in perfect harmony with the frame of smile, face, and above all the patient. On the contrary, any deficiency in or neglect of a single factor will end up with an unpleasant consequence.

2 Hard Tissue at Site of Implant

A key determinant of an aesthetic implant restoration is the existing bone in three dimensions aspect. Adequate bone seems to be essential to enable correct placement of the implant and maintain soft tissue margin and papillae positions.

Based on the evidence available, a minimum 2 mm thickness of buccal bone wall is necessary after implant placement in a healed site to ensure adequate soft tissue support and avoid the complete resorption of the buccal bone wall following restoration [24, 25].

Spray et al. [25] studied the relationship between vertical bone loss and thickness of facial bone on two-stage implants placed in healed sites and detected greater bone loss when the vestibular bone was less than 1.4 mm thick. In contrast, sites with no change in facial bone response had a mean thickness of vestibular bone of 1.8 mm or more at implant placement (Fig. 1).

They concluded that as the bone thickness approached 1.8–2 mm, bone loss decreased significantly and even some evidence of bone gain was seen. Thus, to avoid vestibular bone loss and associated recession, a minimum thickness of 1.8 mm of external bone is required (Fig. 2).

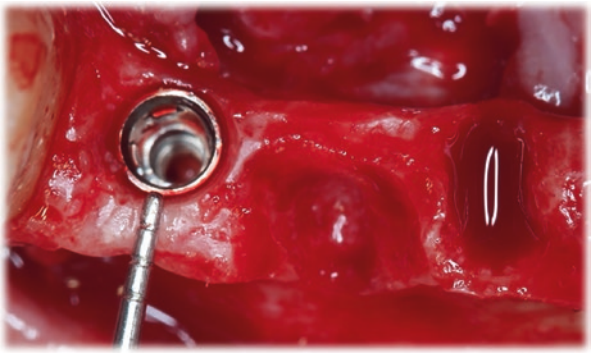

Fig. 1 Two millimeter of buccal bone thickness over the implant replacing tooth #26

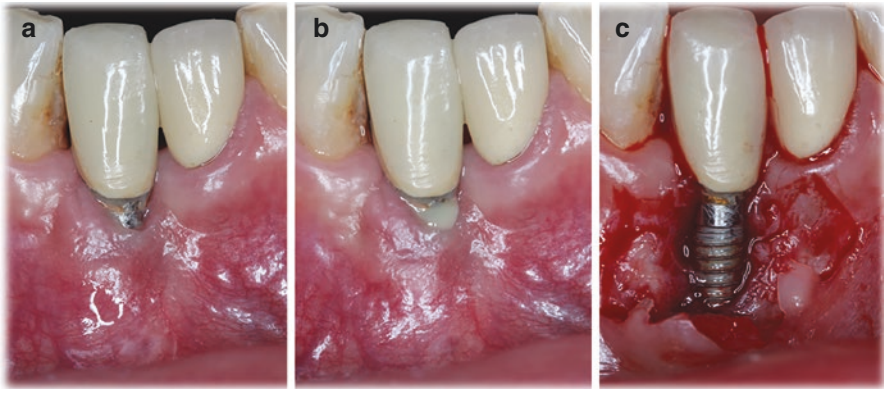

Fig. 2 (**a**) Six-year follow-up on implant #24. (**b**) deep probing depth and suppuration and (**c**) lack of facial bone

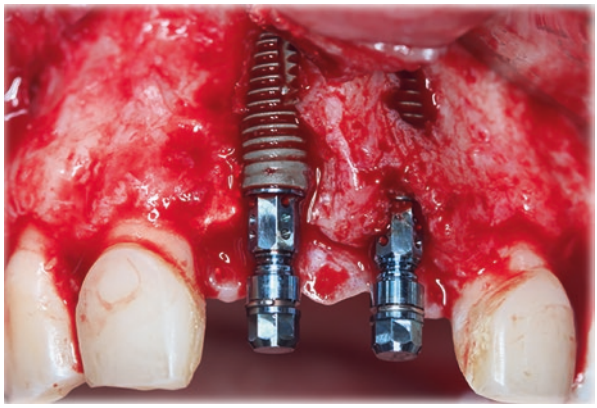

Fig. 3 Lack of adequate facial bone at the time of immediate implant placement

Recently, Barone et al. [26] in a yearlong randomized clinical trial, have reported that sites with a thick buccal bone wall (≥1 mm) seemed to be less prone to buccal mucosal recession than sites with a thin buccal bone wall (<1 mm).

The maintenance of the buccal bony wall seems more essential in cases of immediate implant placement and loading. Kan et al. [27] reported that damage to the buccal bone at the time of immediate implant placement represented a significant risk factor for mucosal recession (Fig. 3).

Nisapakultorn et al. [28] evaluated the association between peri-implant soft tissue recession and buccal bone level and thickness. They displayed that the buccal mucosal level around single-tooth implant was significantly affected by the buccal alveolar crest level and the mean buccal crest thickness decreased as the buccal marginal mucosal level increased, although this association was not statistically significant.

3 Soft Tissue at Site of Implant

In the early days of implant dentistry, most clinicians had focused solely on the quality and quantity of the available bone. As the time passed, it has been understood that soft tissue has played a paramount role in the long-term success and survival of a dental implant.

To evaluate the available soft tissue, a clinician should take two important elements into consideration:

1. Quantity or the tissue biotype.
2. Quality or the availability of keratinized tissue.

3.1 Importance of Quantity (Biotype)

A thin tissue biotype was identified as a risk factor for mucosal recession [27, 29–32]. In a review, Chen and Buser [13] reported that immediate implant placement in sites with a thin biotype had a higher frequency of recession of >1 mm compared with sites with a thick biotype.

According to Nisapakultorn et al. [28], soft tissue biotype was the most significant factor in determining the buccal marginal mucosal level. Therefore, sites with a thin tissue biotype are at greater risk of mucosal recession compared with sites with a thick biotype (Fig. 4).

One could speculate that the connective tissue thickness in the transmucosal area should be at least thicker than the inflammatory infiltrate induced by subgingival plaque or toothbrushing trauma. As the inflammatory infiltrate occupies an area of approximately 1–2 mm [33], a minimum soft tissue thickness of 2 mm is advised to prevent soft tissue dehiscence at the implant-supported crown.

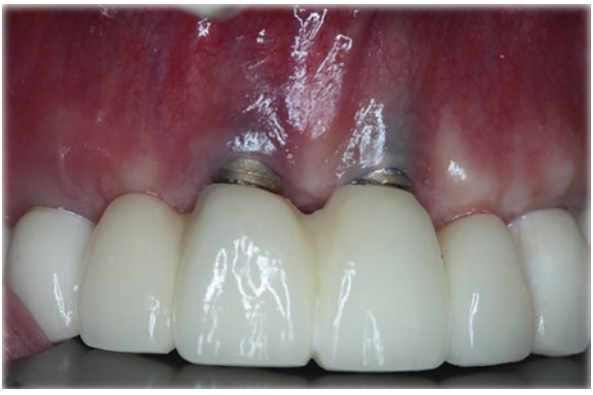

Fig. 4 Thin biotype resulted in facial bone loss and metal shadow appearance on implant #8, 9

3.2 Importance of Quality (Keratinized Tissue)

In addition to biotype, it has been suggested that the keratinization of soft tissues may affect the implant stability [34–36].

In a retrospective clinical trial, Zigdon and Machtei [36] examined 63 functioning dental implants and found more recession in mucosa that was less keratinized. They concluded that these findings were of special importance in the aesthetic zone, where thin, narrow bands of keratinized tissue may lead to greater mucosal recession.

Similar results were found by Schrott et al. [35] while analyzing data from a 5-year prospective multicenter trial. In patients maintaining good oral hygiene and receiving regular maintenance therapy, implants with a reduced width (<2 mm) of peri-implant keratinized mucosa were more prone to buccal soft tissue recession over a period of 5 years (Fig. 5, 6, and 7).

Recently, Roccuzzo et al. [34], in a 10-year prospective comparative study, showed that implants not surrounded by keratinized tissue were more prone to plaque accumulation and mucosal recession than implants surrounded by keratinized tissues.

A systematic review and meta-analyses [37] investigating the effect of keratinized mucosa on implant health concluded that the absence of an adequate band of keratinized mucosa around endosseous implants was associated with greater mucosal recession, as well as plaque accumulation, tissue inflammation, and loss of attachment.

In contrast, Bengazi et al. [38] evaluated the position of peri-implant soft tissue margins after the insertion of fixed prostheses and found that a lack of keratinized mucosa and greater mobility of the peri-implant soft tissues at the time of bridge installation were poor predictors of soft tissue recession occurring during the 2 years of follow-up.

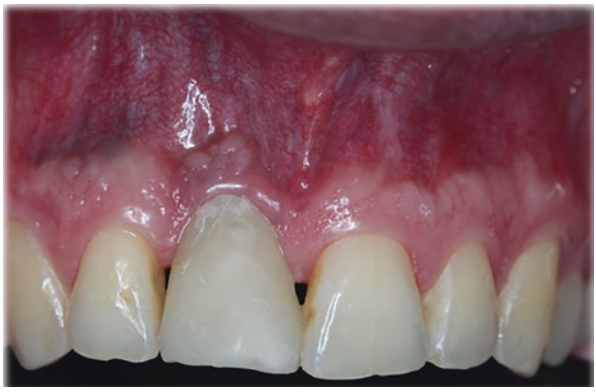

Fig. 5 Soft tissue recession on implant #8

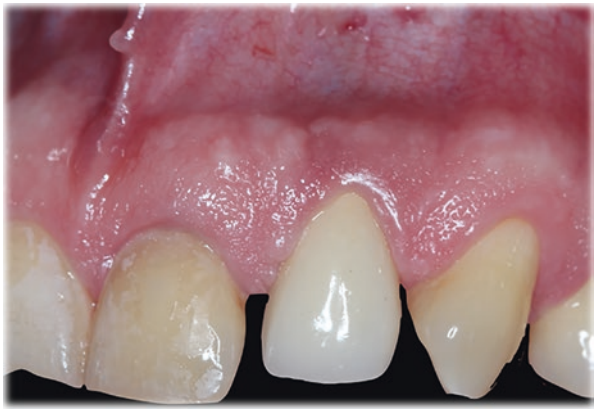

Fig. 6 Soft tissue recession on implant #10

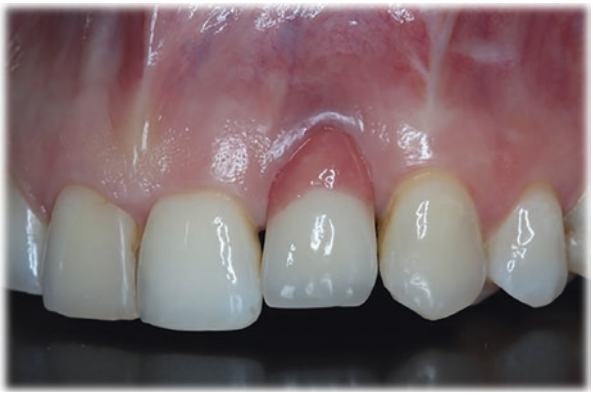

Fig. 7 Deficiency of satisfactory soft tissue followed by using pink porcelain as an alternative ended in an unaesthetic outcome

Despite some discrepancy, most of the recent literature seems to indicate the presence of buccal keratinized tissue as a key factor in improvement of plaque control and minimization of mucosal recession at implant sites, even though the critical width of keratinized tissue value has not yet been clarified [39].

Moreover, another controversial issue would be the need for the surface keratinized tissue versus having a thick biotype without the surface keratinization. This is another question that should be answered.

In regard to soft tissue deficiency and dehiscence around implant, a classification has been recently proposed by Zuccelli et al. [40]:

- Class I: The soft tissue margin is located in an aesthetically correct position (at the same level of the ideal position of the gingival margin of the homologous natural tooth), and the color of the abutment/implant is visible only through the mucosa and/or there is a lack of keratinized tissue/soft tissue thickness.
- Class II: The soft tissue margin is located more apical to the ideal position of the gingival margin of the homologous natural tooth and the implant-supported crown profile is located inside (more palatal) the imaginary curve line that connects the profile of the adjacent teeth at the level of the soft tissue margin.

- Classes III and IV: The soft tissue margin is located more apical to the ideal position of the gingival margin of the homologous natural tooth and the implant-supported crown profile is located outside (more facial to) the imaginary curve line that connects the profile of the adjacent teeth at the level of the soft tissue margin. In these two classes, it is mandatory to remove the implant-supported crown. When the head of the implant is inside (more palatal or at the level of) the straight imaginary line that connects the profile of the adjacent teeth at the level of the gingival margin, the PSTD is defined as Class III, while when the implant head is outside (more facial) this imaginary line, it is referred to as Class IV.

4 3D Implant Positioning

To place an implant, a clinician pays due heed to two major parameters related to the implant position.

Implant should be placed in both prosthesis and biologically driven position and the combination of these two philosophies will acquire an aesthetic end result.

Implants should be placed in a prosthetic-driven position in order to satisfy the parameters of contour which result in a pleasing restoration. On the other hand, it has to be biologically driven to maintain both hard and soft tissue architectures.

The foremost factor that triggers complication seems to be the incorrect placement of the implant in a three-dimensional position, which influences both the hard and soft tissue remodeling processes during healing and after abutment connection in two-stage implant systems [41, 42].

In a retrospective study of the aesthetic outcomes, Evans and Chen [31] found that implants with a buccal shoulder position showed three times more recession than implants with a lingual shoulder position.

Cosyn et al. [43] in a retrospective cohort study, reported that the buccal shoulder position increased the likelihood of mid-buccal recession (odds ratio = 17.2).

The more buccal the position of the implant, the more the mid-buccal margin recedes apically [44]. Likewise, a more proclined implant position and an increased depth of the implant platform significantly increase the risk of buccal recession defects [28].

The 3D implant positioning should be considered in three different aspects:

1. Apico-coronal implant placement.
2. Mesiodistal placement.
3. Facio-lingual placement.

4.1 Apico-coronal Placement

Apico-coronal positioning appears to be the most critical aspect. Deficient tissue in this dimension can result from several factors. The apico-coronal positioning of the implant is the vertical discrepancy between the occlusal surface of the implant and

the peaks of the bony septa proximal to the adjacent teeth. The best aesthetic result occurs when this discrepancy is minimal.

A 4 mm implant needs to be placed 3–4 mm apical to the gingival margin of the contralateral tooth to allow the restoration to emerge with a natural profile.

A vertical distance of 3–4 mm is needed for gradual transition from a 4 mm diameter of the implant platform to the 7–8 mm dimension at the gingival margin. If a lateral incisor is being replaced, the implant would not have to be placed so apically since the average diameter of the crown at the gingival margin is 5 mm and less room is required for transition [23].

Errors in apico-coronal implant placement can have serious aesthetic and biomechanical implications. An implant placed too coronally will not allow adequate transition from the head of the implant to the point where the restoration exits from the free gingival margin. The restoration will look short in comparison to the contralateral tooth [23].

Problems could also arise if implants are placed too apical. Clinically if an implant is placed too apical with excessive countersinking procedures, an unnecessary amount of bone loss will occur. As the bone loss takes place circumferentially, it will affect not only the proximal bone structure, but also the height of the facial bone wall and could lead to undesirable soft tissue contours [45] (Figs. 8 and 9).

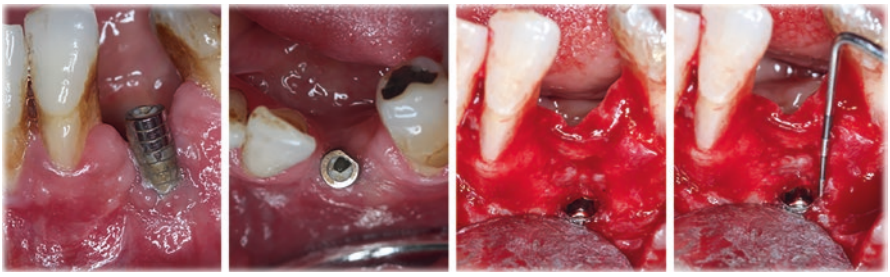

Fig. 8 Multiple errors; implant placed too apically (12 mm from the adjacent teeth CEJ) and far facially where an impression coping utilized as the healing abutment

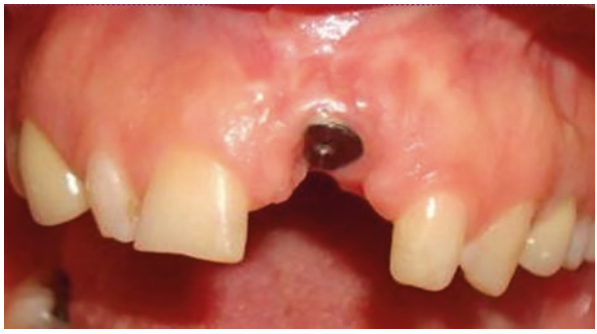

Fig. 9 Multiple errors; implant placed too apically and far facially in the aesthetic zone

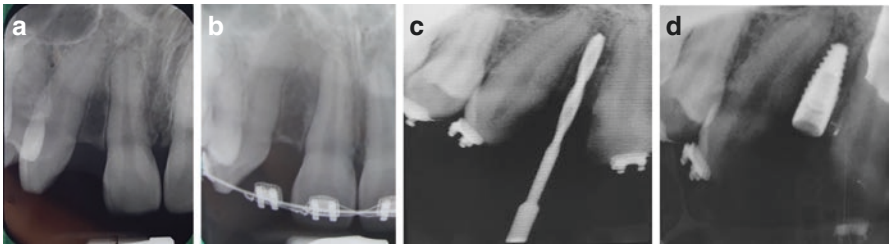

Fig. 10 (**a**) Lack of enough space for implant placement, (**b**) orthodontic therapy for space creation, (**c**) navigating the implant position via radiograph, (**d**) Implant placement

Fig. 11 Multiple errors; two adjacent implants in the aesthetic zone site of #10, 11 placed extremely facially with an improper diameter selection

4.2 Mesiodistal Placement

An implant should be placed 1.5–2 mm from an adjacent root. Placement too close to the adjacent tooth can cause resorption of the interproximal alveolar crest to the level of that on the implant [46, 48].

In cases with minimal space, guided surgery or navigation with multiple radiographs helps reach out to the correct positioning (Fig. 10).

4.3 Facio-lingual Placement

The size of available bone should be at least 1 mm wider than the implant diameter on each side. Hence, a 4 mm-diameter implant requires 6 mm of bone.

The single implant placed in the maxillary anterior region should be situated palatal to an imaginary line that outlines the curve of the arch formed by the facial surfaces of the adjacent teeth [47–49].

In cases that this aspect has not been followed, lack of enough facial bone will result in soft tissue recession, implant exposure, and aesthetic failure (Fig. 11).

5 Single vs. Multiple Implants

Patients with extended edentulous spaces present greater anatomic and aesthetic challenges, making it even more difficult to obtain an aesthetic result with certainty.

Following extraction and wound healing of two adjacent teeth, the ensuing apical and facio-lingual resorption results in an edentulous segment which is flattened. The same diagnostic considerations must be taken into account when dealing with single-tooth edentulous sites. The aim prior to implant placement is to have a three-dimensional configuration of hard and soft tissues that allows placement of implants in an ideal position.

On the tooth implant side, the predictability of the interdental papilla is governed by the height of the interproximal bone crest of the tooth. If the height is favorable, there is a good certainty that the interdental papilla will be maintained following the implant placement [23].

The bone crest between the two implants is likely to undergo further resorption in an apical direction. This is accompanied by a loss of inter-implant soft tissue that in the case of multiple edentulous sites will result in black triangles between the adjacent restorations (Fig. 12).

Many clinicians have sought after the ideal implant distance required to maintain the interdental papilla. Tarnow and colleagues [48] performed a radiographic study to address this clinical problem. Radiographic measurements were taken at a minimum of 1–3 years after the implant exposure. All radiographs were taken with a paralleling technique.

Radiographs were scanned by computer and magnified for measurement. The following measurements were taken:

1. Lateral distance from the crest of the inter-implant bone to the implants.
2. Vertical crestal bone loss.
3. Distance between the implants at the implant/abutment interface.

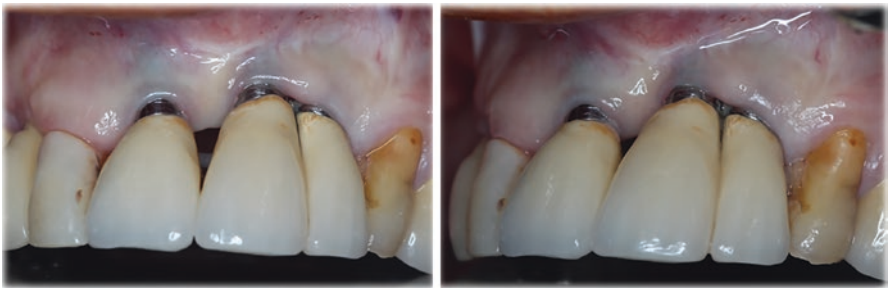

Fig. 12 Multiple errors; three adjacent implants in the aesthetic zone sites of #8–10, placed too far facially, too close mesiodistally on #9, 10 with an improper diameter selection

When implants were placed too close together, the bone remodeling overlapped to a great degree and consequently resulted in loss of vertical bone height which subsequently had soft tissue complications.

When implants were placed 3 mm and greater, lateral bone loss from the adjacent implants did not overlap with minimal resultant crestal bone loss. They concluded that it is more difficult to create or maintain papilla between two adjacent implants than an implant and a natural tooth. They suggested that when two implants are placed adjacent to each other in the aesthetic zone, a minimum 3 mm of bone should be retained between them at the implant/abutment level. Their study specifically addressed bone loss between the implants. It should be remembered that the bone saucerization has two dimensions—a horizontal and a vertical.

Radiographs only demonstrate the horizontal aspect of bone saucerization. Bone loss occurs circumferentially around the implant and when two implants are placed adjacent to each other, facial bone loss also occurs. This has implications in terms of stability of the facial gingival margin. If the implants are placed too far forward, there will be less facial bone and this will ultimately result in apical migration of the free gingival margin.

The placement of adjacent implants is also critical for restorative contours. Placing implants too close together makes it difficult for the laboratory technician to fabricate restorations with pleasing aesthetic contours (Fig. 13).

Tarnow and colleagues [49] also conducted a study to determine the height of the soft tissue to the crest of the bone between two adjacent implants. It was done independent of the location of the contact point.

They looked at 136 inter-implant papillary heights in 33 patients by eight examiners. A standardized periodontal probe was used and placed from the height of the papilla to the crest of the bone. What they found was that the mean height of papilla between two adjacent implants was 3.4 mm with a range of 1–7 mm.

Although this was a retrospective study and there were many variables such as operator, implant type, placement, and so forth, it did give us information that soft tissue between two adjacent implants in the aesthetic zone is not predictable, and

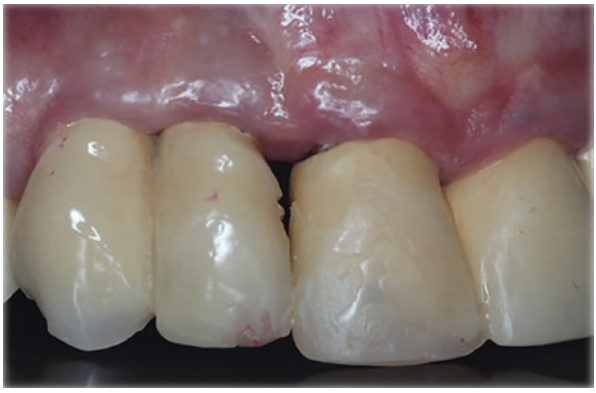

Fig. 13 Two adjacent implants on central and lateral incisors ended up in loss of interproximal papilla

the patient must be informed of it during the treatment planning or alterations must be made in the treatment planning to provide an aesthetic result.

One common error often published in the literature is the placement of four implants to replace lateral incisor to lateral incisor. This philosophy of implant placement will not yield an aesthetic outcome. The placement of two implants in both lateral incisor regions and fabrication of a fixed partial denture sculpting the intervening tissue with ovate pontics are likely to produce an illusion of papilla which will be more pleasing to the observer's eye [23].

6 Impact of Implant Diameter

In addition to correct implant positioning, the diameter of the implant platform seems to play a role in determining the extent of mucosal recession [50, 51] (Fig. 14).

Ross et al. [50] in a retrospective study analyzed the soft tissue margin changes of 47 maxillary anterior single implants over 5 years. The results showed a statistically significant difference between mucosal recession and the different implant diameter at the lateral incisor position (4.3 mm vs. 3.5 mm). The amount of recession was directly linked to the implant diameter.

Small et al. [51] compared soft tissue levels in wide- and standard-diameter implants in a 3- to 5-year prospective study. Wide-diameter implants showed greater mean recession and greater number of sites with recession at the time of prosthesis installation compared with standard-diameter implants. Soft tissue recessions at wide-diameter implants increased during the 5-year follow-up.

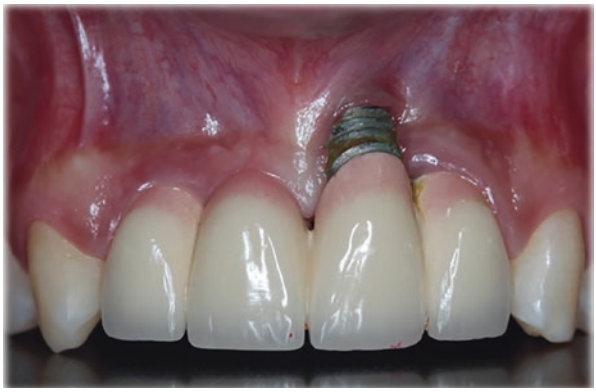

Fig. 14 Improper diameter of implant resulted in bone and soft tissue loss and an aesthetic failure

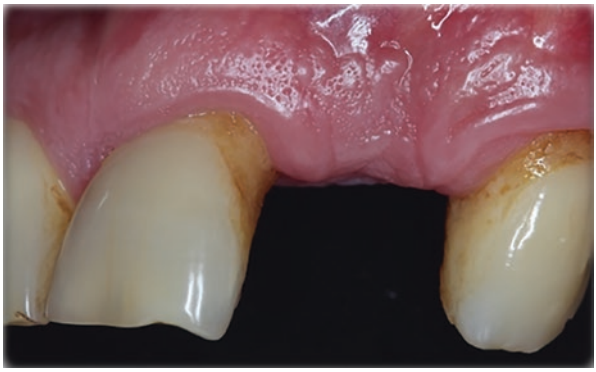

Fig. 15 Lack of bony attachment on distal of tooth #9 ended in a flat papillae. Due to lack of this attachment, the future implant prosthesis will face the same issue

7 Level of Bony Attachment on Adjacent Teeth

For successful aesthetic restoration of implants, the bony housing must have a three-dimensional configuration that permits the placement of an implant in a restoratively ideal position [52]. Kan et al. [53] showed that the height of peri-implant papillae in single-tooth gaps is independent of the proximal bone level next to the implant, but it is dependent on the interproximal bone height of the adjacent teeth (Fig. 15).

Considering implant placement and its relationship with the bone, Nisapakultorn et al. [26] showed that the level of the first bone-implant contact and the interproximal bone crest were associated with the buccal soft tissue level. In this study, the increase of distance from the contact point to the bone crest and from the contact point to the first bone-implant contact significantly raised the risk of buccal marginal mucosal recession (odds ratios = 3.4 and 2.4, respectively).

In such cases, only the prosthesis design is able to compensate the lack of the papilla by filling the gap with restorative materials.

8 Timing: Immediate, Early, Late

The relatively high prevalence of a midfacial peri-implant soft tissue deficiency that can range up to 64% in immediate implants [54] can be attributed to many predisposing and triggering factors including: a buccally positioned implant, a dehiscence or fenestration at the buccal bone, a thin gingival biotype, a lack of or a minimal keratinized mucosa, vigorous tooth brushing, inflammation, and an over contoured prosthesis [55].

Immediate implant placement was associated with greater variability in aesthetic outcomes and a higher frequency of a mucosal recession of >1 mm midfacially (median 26% of sites), when compared with early implant placement [5].

However, it was noted that to minimize the risk of recession of the midfacial mucosa, the majority of studies published after 2008 used selection criteria by including only sites with an intact facial bone wall and medium to thick tissue biotypes [5].

The problem of soft tissue recession was also identified with the first radiographic studies examining the presence or absence of the facial bone wall at immediately placed implants with three-dimensional cone beam computed tomography (CBCT) imaging. The first CBCT studies showed surprisingly high values of a missing facial bone wall in CBCT images ranging from 24% to 57% [56–58]. Sites with the absence of a detectable facial bone wall were associated with greater mucosal recession.

With the knowledge of CBCT studies, the ITI Consensus Conference came up with clear recommendations on the time of using each treatment option [59].

Immediate implant placement (type 1) is regarded as a complex procedure and should only be performed by master clinicians, when ideal anatomic conditions are present.

This includes (1) a fully intact facial bone wall at the extraction site with a thick wall phenotype (>1 mm), (2) a thick gingival biotype, (3) no acute infection at the extraction site, and (4) a sufficient volume of bone apical and palatal of the extraction site to allow implant insertion in a correct 3D position with sufficient primary stability.

When these ideal conditions are not met, the ITI recommends early implant placement after 4–8 weeks of soft tissue healing (type 2).

In cases that primary stability cannot be achieved after 4–8 weeks, the post-extraction healing period should be extended to allow partial bone healing (type 3) [5].

The following is a list of anatomical structures to examine in a single-tooth extraction site in the aesthetic zone [5]:

1. The thickness, height, and integrity of the facial bone wall.
2. The height and thickness of the palatal bone wall.
3. The crest width mesially and distally to the extraction site, measured 3 mm apical to the cemento-enamel junction (CEJ) of adjacent teeth.
4. The height and inclination of the alveolar ridge.
5. The height of the alveolar bone at adjacent teeth.
6. The location and extension of the nasopalatal canal.
7. The bone volume available apically and palatally of the root.
8. The mesiodistal size of the post-extraction single-tooth gap.

8.1 Indications for Immediate Implant Placement

Immediate implant placement can be used in ideal clinical conditions. The most important requirements are a fully intact facial bone wall with a thick wall phenotype (>1 mm) and a thick gingival biotype (Fig. 16). When both conditions are present, there is a low risk for recession of the facial mucosa and orofacial flattening of the soft tissue profile at the neck of the implant prosthesis.

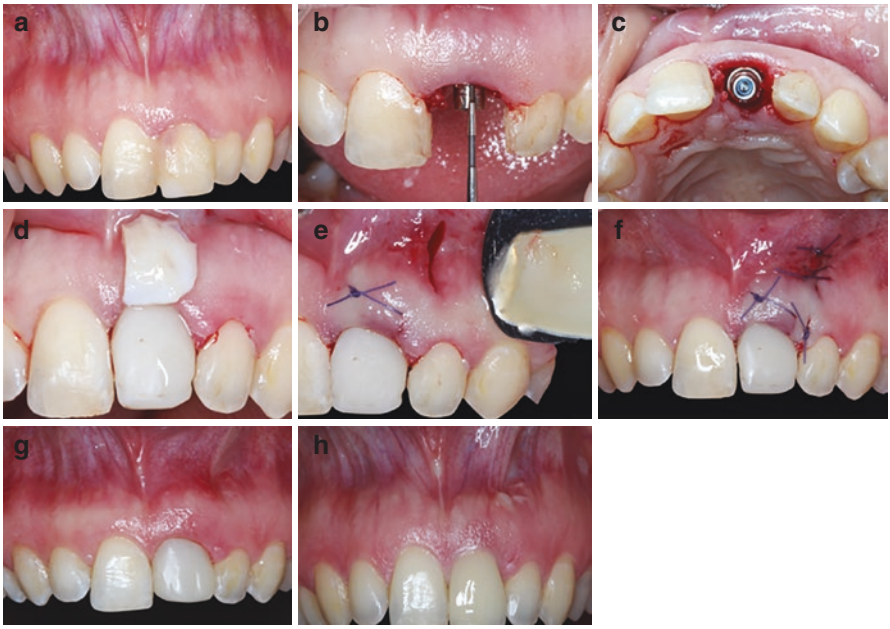

Fig. 16 Sequence of immediate implant placement/provisionalization # 9. (**a**) Extraction, (**b**) immediate implant placement, soft tissue graft with (**c**, **d**). CTG using VISTA technique, (**e**, **f**) delivery of immediate temporary restoration, (**g**) final restoration

In addition, there should be an absence of acute purulent infection in the extraction site and a sufficient bone volume apically and palatally of the extracted root to allow a correct 3D implant positioning with good primary stability. These conditions are infrequently encountered in the anterior maxilla. According to various CBCT studies, a thick wall phenotype is rarely present in the anterior maxilla [60–62].

The study by Braut et al. [60] analyzed the facial bone wall thickness at various tooth positions in the anterior maxilla. In central incisor sites, only 4.6% had a thick wall phenotype (>1 mm), whereas this condition was present in 27.5% of the first premolar sites.

Behnia et al. [63] showed the mean thickness of the labial alveolar bone overlying maxillary anterior teeth was found to be between 1 and 1.2 mm and between 0.5 and 0.8 mm for mandibular anterior teeth at the first 5 mm from bone to crest in a group of Iranians.

8.2 Indications for Early Implant Placement with Soft Tissue Healing in 4–8 Weeks

The concept of early implant placement with soft tissue healing (type 2) was developed in the late 1990s. It requires a 4–8 week healing period following extraction

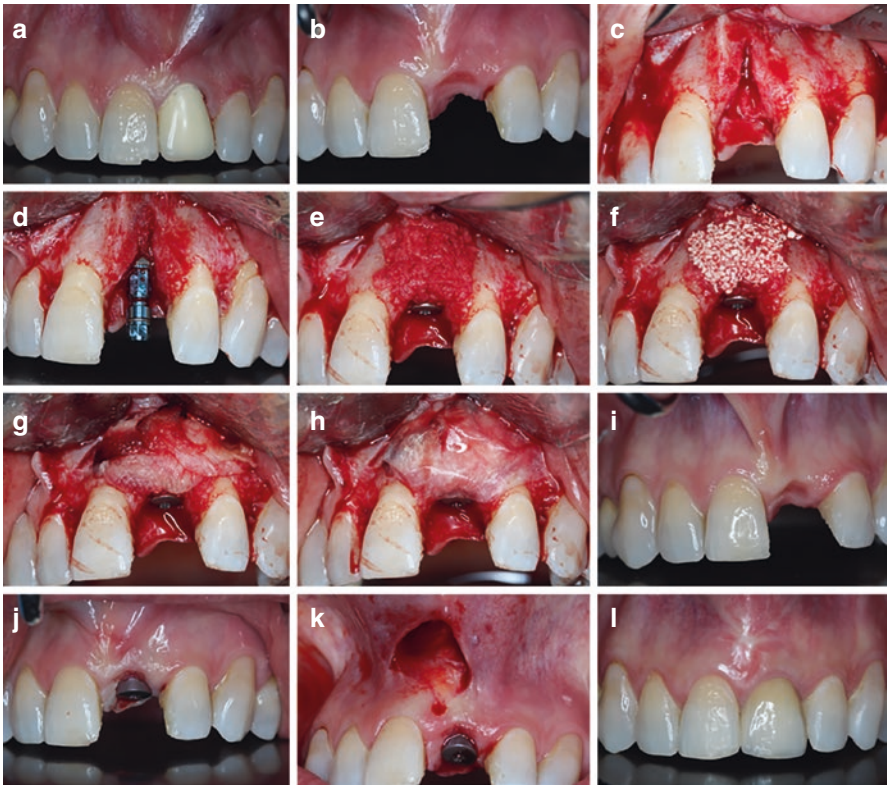

Fig. 17 Sequence of an early implant placement # 9. (**a**) Extraction, (**b**) 6 weeks later, (**c**, **d**) implant placement with GBR with (**e**) autogenous, (**f**) xenograft, (**g**) PRF and (**h**) membrane. (**i**) Second stage with (**j**) frenectomy. (**k**) Final restoration

before implants are placed. During the period, several biological events take place which help the clinician and the patient as they facilitate the surgical procedure and reduce the risk for postsurgical complications (Fig. 17).

The advantages are: (1) The soft tissues will spontaneously heal providing 3-5 mm of additional keratinized mucosa in the future implant site; (2) the bundle bone will resorb, which mainly affects the midfacial aspect of the extraction socket during the initial wound healing phase. This phase is dominated by a high osteoclastic activity resorbing the bundle bone delineating the extraction socket; (3) a spontaneous soft tissue thickening will take place in sites with a thin facial bone wall phenotype or in sites with a damaged facial wall.

A recent study by Chappuis et al. [64] demonstrated a sevenfold increase of the soft tissue thickness in such situations in the midfacial region. This offers several advantages for the surgeon including a thick mucoperiosteal flap for implant surgery, an enhanced vascularity in this flap improving the healing capacity, and a potential reduction of the need for connective tissue grafting for soft tissue augmentation; (4) if present, acute or chronic infections or fistulae at the extraction site will

resolve offering a future implant site with a reduced bacterial risk; and (5) at the apical portion of the socket, new bone formation will have taken place. This enables an easier implant bed preparation when compared with a fresh extraction socket.

8.3 Indications for Early Implant Placement with Partial Bone Healing in 12–16 Weeks

This approach is used in patients when an extended periapical bone lesion is present that does not allow implant placement in a correct 3D position with sufficient primary stability by immediate (type 1) or early implant placement (type 2). These situations, which are rare in the maxillary anterior region, require a slightly prolonged socket healing period for further new bone formation in the apical area. It should be noted that early implant placement with partial bone healing (type 3) is ideal for the replacement of multirooted teeth, such as mandibular first molars.

9 Immediate Implant Placement, Immediate Provisionalization

There are controversial results in the literature regarding the use of implants with conical connection and platform switching to limit mid-buccal recession [65, 66].

Immediate provisionalization of an immediate single-tooth implant has been proposed to optimize the aesthetic outcome. De Rouck et al. [67], in a yearlong randomized clinical study of 49 patients, showed that the mid-buccal recession was 2.5–3 times higher in the delayed restoration group compared with the immediate restoration group, showing a mean difference of 0.75 mm at study termination and favoring immediate restoration (mid-buccal recession was 1.16 mm in the delayed restoration group and 0.41 mm in the immediate restoration group).

However, two other randomized controlled clinical trials [68, 69] found no statistically significant difference in mucosal recession between immediate and conventional loading implants placed into sites with healed soft tissues 1 year after the final restoration. Similarly, one study showed significantly less mucosal recession when a flapless surgical approach was used [70] but other studies failed to support it [27, 71].

10 Patient Selection and Smile Line

Lip length, lip activity, and occlusion of the patient are very important issues and should be paid due attention to in the treatment planning. Short upper lip, vertical maxillary excess, excessive gingival show, deep-bite, open-bite, dental midline deviation, Class II or Class III canine relationship, high smile line and asymmetric muscle activity are among the challenging factors facing the planning for the implant in aesthetic zone.

11 Clinical Skill and Experience

Skill and experience of the clinician play an important role in treatment planning as well as surgical and prosthetic procedures in aesthetic zone.

12 Surgical Intervention for Correction of Aesthetic Failures

The surgical techniques reported in the literature and analyzed in a review by Mazzotti [39] can be categorized into different groups:

- Coronally advanced flap with or without (envelope coronally advanced flap) vertical releasing incisions supplemented by connective tissue graft.
- Envelope flap/pouch/tunnel techniques with connective tissue graft or collagen matrix.
- Submerged techniques with or without connective tissue graft.
- Pedunculated connective tissue graft.
- Free gingival graft.
- Multiple surgical approaches in different surgical steps.

Recently, the vestibular incision subperiosteal tunnel access (VISTA) technique has been introduced by Zadeh [72] that involves making a vestibular incision in a remote area from the targeted area of the recession. Then a subperiosteal tunnel will be made toward the recession and flap will coronally advance via bonded suture. Then connective tissue graft or biomaterials shift and fix through the vestibular incision.

So far, there has been no adequate reason to prove one of the treatment approaches the most effective and predictable.

13 Clinical Cases

13.1 Case 1

The patient was a 56-year-old male, with a chief complaint of "my implant is getting longer." The implant had been placed for him 7 years ago. There was a recession detected on implant #10 (Fig. 18). The technique used in this case was VISTA, a vestibular incision made mesial of #10 in a remote area from the site of the recession. A subperiosteal flap was made and connective tissue was harvested from the tuberosity. The graft was fixated, flap coronally advanced by using the bonded suture, and platelet derivative was added to the site to prompt the sequence of the soft tissue healing. Postoperative instruction and medication were given. Sutures were kept for three weeks and then removed. A glance at the site at the postoperative stage showed the clinician that the recession area was covered with a thick mucosal biotype.

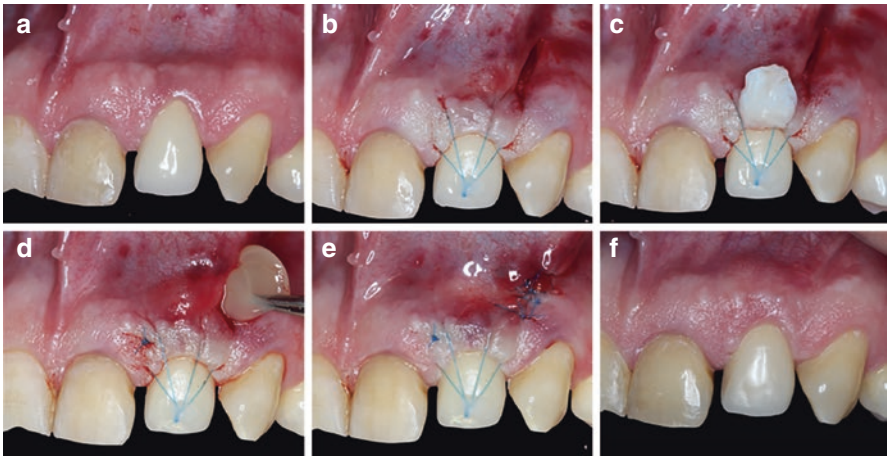

Fig. 18 (**a**) 7-year follow-up on implant #10 with recession and thin biotype. (**b**) vestibular incision, (**c**) subperiosteal tunnel with coronally advanced flap via bonded suture. (**d**) CTG from tuberosity, (**e**) platelet derivative added, (**f**) flap closure. (**g**) One-year follow-up demonstrated thick biotype with more coronally marginal mucosa

13.2 Case 2

The patient was a 45-year-old female, with a chief complaint of "there is a huge bump on my implant." The implant had been placed for her 3 years ago. There was a bump detected on implant #4 (Fig. 19). Due to the pathologic nature of the lesion, biopsy with a millimeter of normal margin has been done, which ended up with outstanding amount of tissue loss at the aesthetic zone. An epithelialized vascular interpositional graft was harvested from the edentulous area of #3 and graft was fixated to cover the biopsy site. Sutures were kept for two weeks. A year later, mucosa around the implant was stable.

The pathologist report was pyogenic granuloma.

13.3 Case 3

The patient was a 78-year-old male, with a chief complaint of "I can see the metal in my mouth." The implant had been placed for him 5 years ago. Due to very thin biotype, it was assumed that it was the major cause of the facial bone loss, making the implant visible through the mucosa (Fig. 20).

The VISTA technique was used in this case, flap coronally was advanced via sling sutures while anchored. Connective tissue graft from tuberosity in addition to the platelet derivative was utilized.

The main goal in this case was to change the biotype from thin to thick as well as masking the metal show.

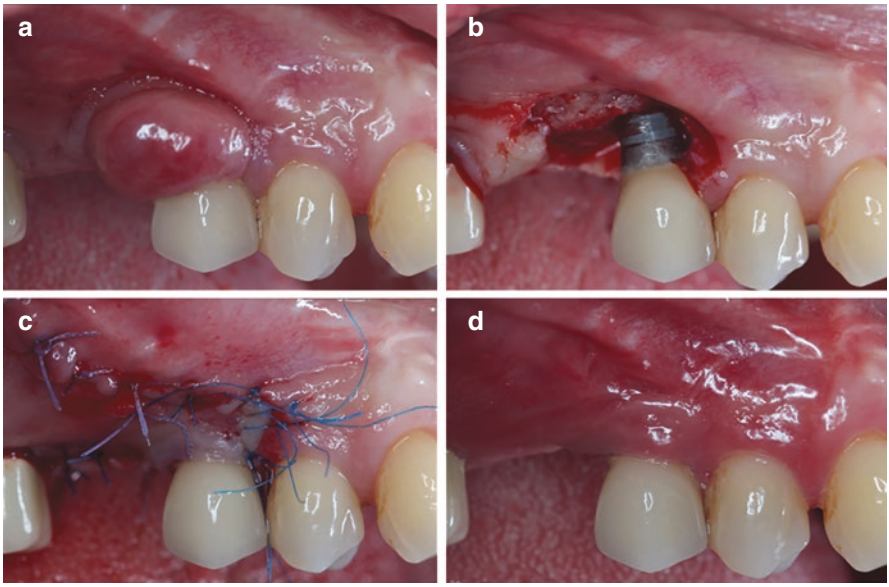

Fig. 19 (**a**) Pathologic lesion at the facial aspect of implant #4, (**b**) lesion excised for biopsy, (**c**) flap rotated from the adjacent edentulous area and sutured to cover the excised lesion. (**d**) One-year postoperative with a stable tissue on the previous pathologic site

13.4 Case 4

The patient was a 42-year-old male, with a chief complaint of "my gum is going up around my implant." The implant had been placed for him 4 years ago. There was a recession detected on implant #8 (Fig. 21).

Prosthesis was removed, incision was made according to the incision purposed by Desanctis and Zuccelli [73] for coverage of single recessions in a partial-full-partial thickness manner from coronal to apical, connective tissue graft was harvested from the tuberosity and fixated, platelet derivative was added, and flap coronally advanced and was sutured. Prosthesis was adjusted to the new level of the mucosal margin. Sutures stayed for 2 weeks. Postoperative photos showed the coverage of the mucosal recession as well as thickening of the tissue biotype.

13.5 Case 5

The patient was a 24-year-old female, with a chief complaint of a dramatic aesthetic issue on her front implant, which had been placed 2 years ago (Fig. 22). Implant #8 had been placed too far facially as well as extremely apically.

The implant was removed, the site was irrigated, and a period of two months was given for soft tissue healing. The process of bone augmentation was done, using

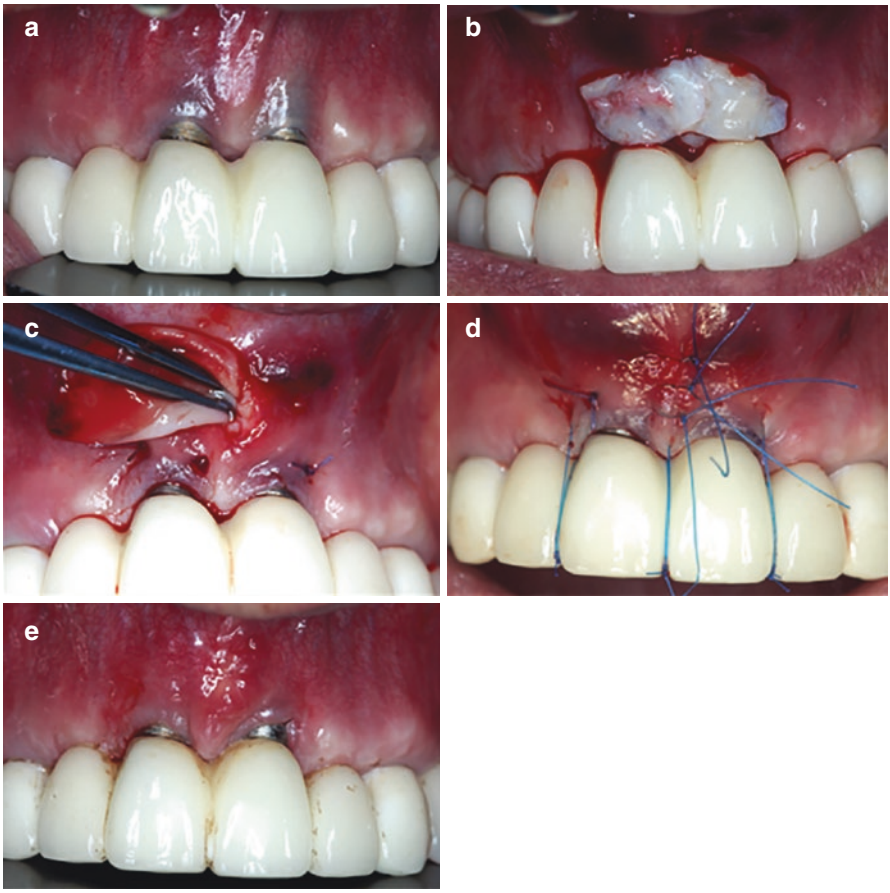

Fig. 20 (**a**) Mucosal recession and metal show on implants #8, 9 due to very thin biotype. (**b**) VISTA technique using CTG from tuberosity, (**c**) platelet derivative added, (**d**) flap coronally advanced, (**e**) 2-year follow-up showed significant decrease in the metal show despite lack of success in complete recession coverage

fixating block bone grafts with xenograft material. Six months later, with the appreciation of both soft and hard tissue healing, the implant was placed.

Two months later, the final prosthesis was delivered, which generated an enormous difference between the patient's initial smile and the final result.

13.6 Case 6

There are some complex cases that the clinician will not able to achieve an optimal outcome via conventional techniques. Utilizing these techniques will end up with aesthetic failures and complications (Fig. 23).

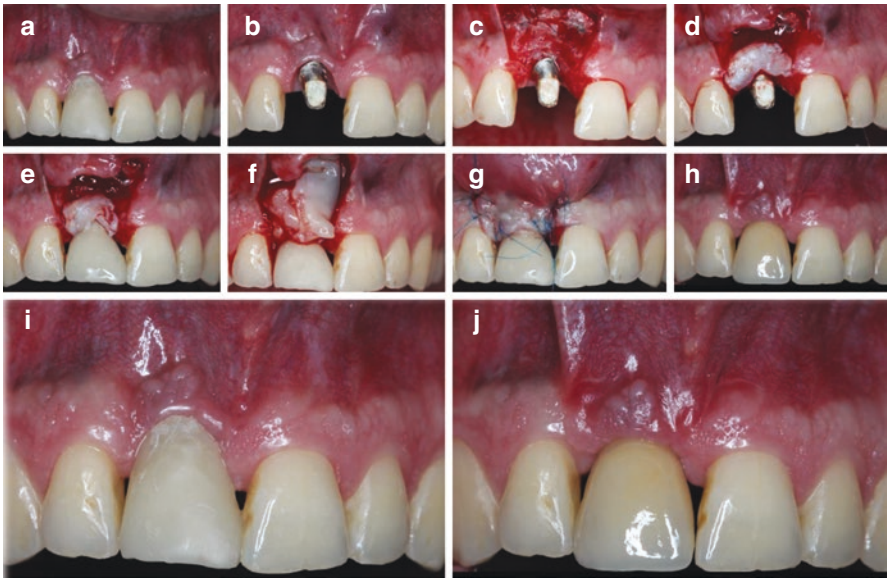

Fig. 21 (**a**) Soft tissue recession at the site of implant #8, (**b**) prosthesis removal, (**c**) incision design, (**d, e**) CTG from tuberosity, adaptation, and fixation, (**f**) platelet derivative, (**g**) flap closure, (**h**) final prosthesis, (**i**, **j**) comparison of pre- and postoperative demonstrates more coronal level of the marginal mucosa and thicker biotype

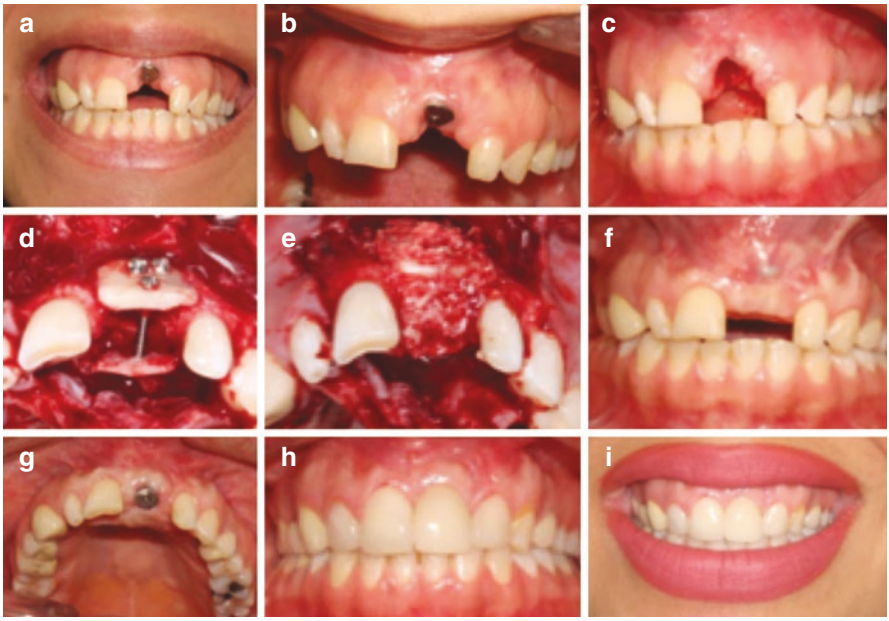

Fig. 22 (**a**, **b**) Ailing implant poorly placed overly far facially and apically, (**c**) explanted, (**d**, **e**) block bone graft done, (**f**) 6-months healing period, (**g**) implant placed, (**h**, **i**) final prosthesis delivered

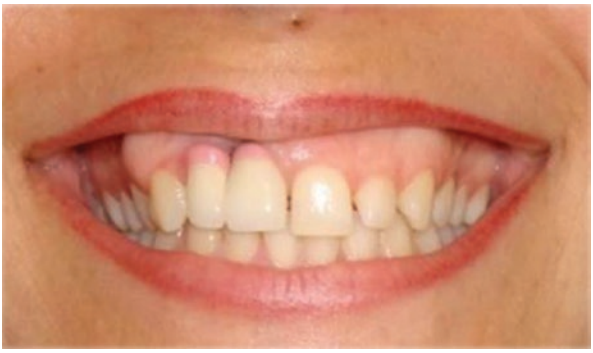

Fig. 23 Aesthetic failure of vertical augmentation due to mismanagement of technique selection

In cases with severe lack of hard and soft tissues or presence of scar tissue, it is better to avoid using intraoral graft and instead use extra oral free vascularized grafts, like fibula grafts [74, 75] or use some complex techniques such as distraction osteogenesis (D/O).

Distraction osteogenesis is a complicated approach, which is mainly used for vertical augmentation in the severe vertically resorbed areas. Behnia et al. evaluated the efficiency of D/O in the anterior maxilla and mandible and reported that the amount of obtained vertical augmentation was between 5 and 15 mm [76].

The patient in Fig. 23 referred to an oral and maxillofacial surgery department due to severe horizontal and vertical bony loss on the area of #10, 11, 12. The sequence of D/O has been demonstrated in the panoramic views (Fig. 24). The D/O device has been removed. Implants have been placed, and additional GBR have been done.

One of the major disadvantages of this technique is the lack of control over the path of augmentation along with the necessity of performing horizontal bone augmentation in a later stage.

The patient received the final prosthesis.

14 Conclusion

This chapter demonstrated the delicacy and intricacy accompanied with the dental implant treatments in the aesthetic zone. When the clinician has the full control over the area and starts a case from the very beginning, all necessary pre-operative evaluations followed by step-by-step operative and postoperative approaches should be taken into account in order to obtain an ideal result.

However, if a complication, either in soft or hard tissue, occurs as it has been displayed in the clinical cases, it is extremely difficult to obtain an ultimate result. All the surgical approaches improved the situation by making it less complicated. So, a clinician is expected to spare no effort to prevent such aesthetic complications.

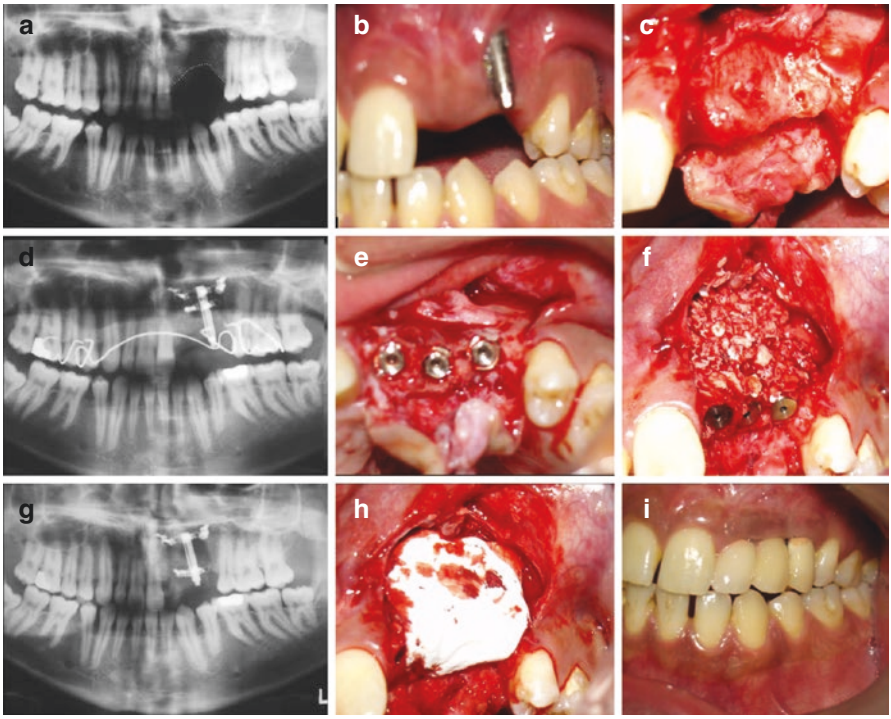

Fig. 24 (**a**–**c**) Sequence of D/O through panoramic radiographs, (**d**) D/O device, (**e**) augmented bone, proper vertical with lack of adequate horizontal augmentation, (**f**) implant placed, (**g**, **h**) GBR for horizontal augmentation, (**i**) final prosthesis

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Infectious Dental Implant Complications

Bedrettin Cem Sener

1 Introduction

In daily practice the increasing number of dental implant use, unfortunately, without any doubt brings higher failure risks at the same time. Failing implants do not only cause delays on restoration agenda but also financial losses of the clinician. Moreover, those failures could harm patient–clinician bond and lead medicolegal issues. Beginning from patient selection to postoperative follow-up, many reasons might cause bone loss and failure of the implant. The peri-implant disease does not have to be progressive, if any necessary measures are taken. Owing to this multifactorial basis, peri-implant related problems cannot be related and limited to infectious diseases only. With this regard, all the factors that might lead failure should be assessed and eliminated before, during, and after implant placement. Therefore, the clinician has the responsibility to analyze the patient's complaint and need, evaluate the medical history, occlusion, oral soft tissue condition, oral hygiene level, current intraoral problems thoroughly, make a proper treatment plan, and execute the ideal plan with high precision and follow the recall agenda strictly. Also, the clinician should be capable of management of the complications. Without evaluating all factors that might play a role in development of peri-implant disease, the decontamination of implant surface might not be successful. This chapter draws the reader's attention not only to the infectious diseases and their management but also other causative factors that play a critical role in implant survival, and preventive measures. Within this widened spectrum, peri-implant tissue diseases and their relations with surrounding structures are addressed to give a broader perspective with most recent literature review.

Within this context, the reader will get detailed information in the other chapters of this book to relate the cause and the outcome perspectives in a way to imply the

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importance of preventive measures of implant-related infections. Especially, the solutions for marginal bone loss issues are given from an etiology-based perspective, and compromised management strategies are also given within this context.

2 Description

Rise of the incidence of peri-implant diseases is inevitable by the increasing number of implant applications in daily practice [1]. The most used term to describe the peri-implant diseases limited to infectious diseases is peri-implantitis (infection of bone surrounding the implant-irreversible form) and peri-implant mucositis (mucosal inflammation around the implant-reversible form) [2]. However, the pathognomonic changes around implants cannot be restricted to infectious diseases only. Similarly, a variety of pathologies could cause peri-implant bone loss. Even the peri-implant tissue diseases are not limited to bone losses, but corrosion-related problems are evident in the literature. Especially, without searching objectively the reason for failure, the salvation attempts would inevitably be unsuccessful, if the clinician focuses on only cleaning the implant surface and replacing the missing bone. For the reason that, if all mandatory steps of the implant application can be fulfilled the long-term success can be achieved. The failure is certain if any of those rings are weak in the chain. In this analytic understanding, the clinician should overview all the possible factor(s) that might cause failure of the implant. Also, it should be considered that most of the implant failures occurred at the first few years after implantation [3].

3 Etiology

Osseointegration of an implant and its continuity over the years is closely dependent on proper case selection as well as clinical application. The progressive bone loss around the implant may mislead the clinician to a peri-implant infection at first sight. However, several systemic and local factors impact bone integrity around the implant in the long run. Those factors can initiate and induce bone recession, which ends up exposure of rough surface into the mouth. Increased surface porosity would induce biofilm formation and makes the removal of the microbiome difficult or impossible. As a natural outcome, raised biofilm deposition and challenge of its removal makes the implant more vulnerable to infection. In this perspective, evaluation of the patient before the planning stage has a vital value for the osseointegration and prognosis. These concepts are discussed within other chapters of this book. Therefore, those critical values should be well digested by the clinician as the initial mandatory steps on the success path.

3.1 Physical and Thermal Effects

Dental implants are designed to mimic the missing teeth and biomechanically function in different living tissue layers, like bone and gingiva. Their function and

survival are closely dependent on their relations with those tissues while protecting their integrity against the oral flora invasions. Regarding all these connected factors, initial connection with the bone depends on frictional forces between implant and bone surfaces, which is also called as primary stability. Following the placement of the implant biologic connection between the implant and bone develops gradually—secondary stability, while mechanical attachment decreases with bone remodeling. When the loading protocols considered, the value of primary stability has become a focus of many study groups.

With these regards, any factor that violates this relation and bonding ability would lead to failure of the implant. These injuries can occur in different stages as follows:

3.1.1 Intraoperative

During the implant placement procedure, the implant-to-bone contact is aimed to be at maxumum level, however, this can be disturbed due to improper technique and end with weak primary stability. Besides the patient-related factors, like bone quality and quantity values, especially undersized preparation of the implant site can be the core of primary stability issue. By using conventional twist drill systems, over-drilling of the implant bed diameter is possible [4] and has been shown to lead to loss of primary stability. Similarly, use of piezo-surgery tool can also oversize bone preparation and cause a limited decrease of ISQ values and in the earlier osseointegration phases, but gradually increase by the time [5]. On the other hand, the use of a surgical drill template has shown to achieve more predictable clinical bone-bed diameter in in vitro studies [6].

Similarly, insertion torque during the placement of implant gains an important role to optimize the balance between bone healing while achieving the primary stability. The clinician should realize that increased insertion torque can cause compression forces, especially with D1 and D2 bone and with aggressive thread shapes, around the crestal bone around the implant collar area. This compression would cause vascular compromise and eventually end with marginal bone loss. Therefore, the equilibrium between the under-drilling and insertion torque should be tailored to each implant site considering the bone quality. When the bone quality is regarded, obviously over-drilling should be predicted as a higher risk for looser bone types, like D3 and D4. Exclusively, in the osteoporotic, or elderly patients or in maxilla-comparing to-mandible have a higher risk of over-drilling and losing the primary stability.

To minimize over-drilling:

- The bone quality should be evaluated on the preoperative cone-beam computerized tomography (CBCT) scans and a drilling strategy should be determined. Notably, the under-drilling can be kept at a minimum threshold for D1 and D2 bone, while could be maximized for poorer bone quality (D3 and D4 bone).
- Use of fully guided surgical templates can be considered for inexperienced clinicians. Even with an experienced hand constitution of long axis parallelism for full arch procedures might require computer-guided template assistance at least for pilot drills. Particularly, in multiple implant cases without template guidance, the clinician would possibly need to obtain optimum parallelism among the implants by long axis adjustments between drillings. During the long axis

adjustment of the implant while insertinf the implant into its bed, it can potentially lead to excessive bone removal in implant beds that would end up with loss of primary stability. Therefore, clinician could consider the use of a template for more than three implant placements where parallelism is essential.

- Up-down movement of the drill should be avoided to minimize excessive bone removal during osteotomy [7].
- Similarly, bone tapping, especially recommended high bone densities for a stress-free adaptation of the implant to its bed, particularly at the cortical bone. The tapping for D3 bone can be limited to cortical bone only, while it can be avoided completely for D4 bone type.
- Likewise, insertion torque can be a good indicator for primary stability [8]. To minimize this spinning effect of tapping instrument, which ends up with a loose bone cavity; during bone tapping the hand torque instrument (rachet tool) should be carefully stabilized along the long axis of the drilled cavity. Likewise, the same cautious effort must be spent during implant insertion to diminish over-prepared implant bed (Fig. 1).

When the clinician feels a resistance to insertion of the tapping tool or implant under torque, should remove the tap or implant gently. Otherwise, if tapping or implant insertion is continued against resistance axial tilting and over-sizing of the implant cavity is possible. Last drill sequence can be reassured before tapping.

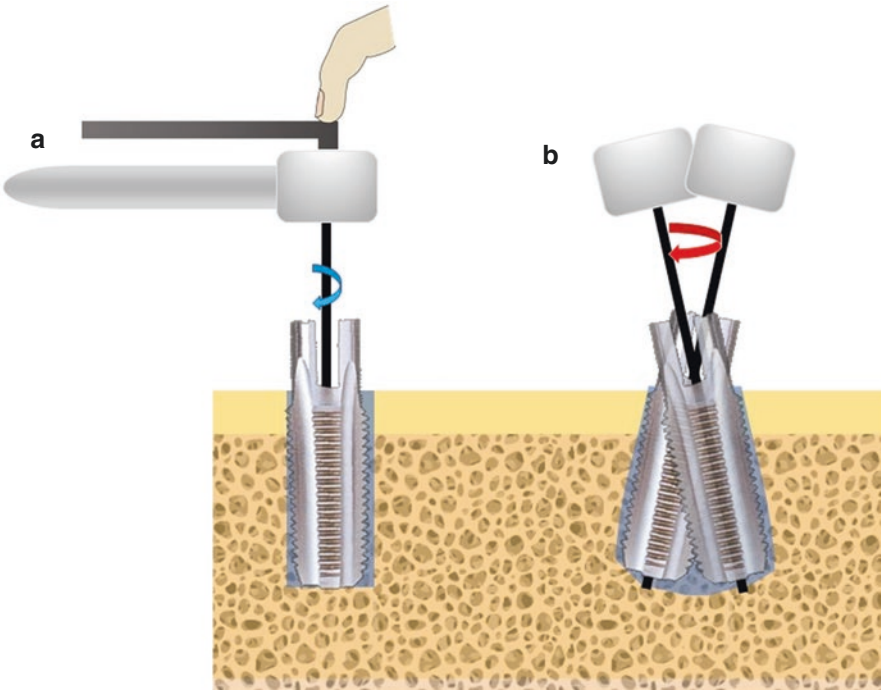


Fig. 1 (**a**) Controlled tapping of bone. (**b**) Unsupported ratchet causes over-sizing the implant bed

On the contrary, if the clinician notices the over-sized implant bed during implant insertion, should consider using a larger diameter of implant. Similarly, as the vertical height of bone allows, deepening the drilling and placing a longer implant can be an alternative solution. If the stability of the implant is questionable, removal of the implant and bone grafting of the site and placement of implant following the graft healing can be more predictable.

It is critical to make a clear decision to either remove or leave the implant for survival when the primary stability of an implant is not satisfactory during the procedure. There are some studies to assess the stability of implant relying on implant stability quotient (ISQ) or insertion torque values [8, 9].

The primary stability of the implant relies on the optimum difference between drilling and the implant diameter. In contrast, if the bone cavity is prepared narrower than the optimum diameter, the implant would apply excessive compression on the surrounding bone. This pressure on the tissue would lead to early bone resorption around, which could interfere in implant survival. Due to its compact structure, cortical bone is more likely to receive and resist these compression stresses, while spongious bone can easily deform and adapt to those strains. Therefore, middle and apical thirds of the implant have a higher chance to integrate earlier than the neck side [10]. The overloading on the cortical bone can diminish perfusion leading to early bone recessions and may cause stress cracks on the neck area [11]. Therefore, adaptive marginal bone losses would most likely occur at neck area at the initial phase. However, it has shown to be irrelevant with long-term failure risk [12, 13].

Alternatively, the implant can be overloaded due to excessive occlusal forces due to poor prosthetic design or bruxism, etc. causes progressive bone loss and failure [14, 15]. Hence, when a peri-implant bone loss is faced, the clinician should initially search and eliminate those biomechanical factors, instead of making debridement and decontamination of implant surface only. Hereafter, the prosthesis can be modified or removed to minimize or eradicate occlusal overloading. Then progression of bone loss should be assessed besides oral hygiene evaluation. Additionally, improvement of oral hygiene maintenance is necessary for the recovery of the peri-implant bone losses.

Another significant factor that impedes bone healing and leads failure is the thermal damage during the drilling sequence. It has been documented that rotary cutting generates frictional heat. Any temperature elevation exceeding 47 °C would result in a certain extent of necrosis of the surrounding undifferentiated and differentiated cells [16]. Notably, the cortical bone is more prone to heat increase during drilling [17]. Good bone quality, like D1 and D2, sharpness of drills [18], high drilling speeds, applied pressure during drilling [19], increased drilling time and frictional forces due to deep drilling lengths [20], and insufficient irrigation due to the use of surgical guides [21] have been shown to cause increased thermal damage on the bone. Therefore, to minimize the heat damage copious irrigation during drilling, cooling saline flashes between drilling sequences, using cool irrigation fluid, and sharp instruments with advised drilling speed (<2000 RPM) should be followed. Also minimizing pressure on the handpiece and moving the drill gently in up-down

direction can reduce the thermal injury-related bone necrosis risk. Drilling sequence described by the manufacturer should also be followed, and no intermediate drilling steps should be skipped. Additionally, as the surgical templates might shield the bone surface from irrigation solution during the drilling sequence and can cause overheating at the bone due to lack of cooling effect. Therefore, additional irrigation canals should be created on these templates, so thet more generous irrigation solution can reach the drilling site for better cooling effect.

3.1.2 Immediate Implant Placement to Fresh Extraction Site and/or Immediate Loading

This concept has been developed for specific cases, as described in another chapter of this book in detail. Arbitrary applications of immediate placement or immediate loading protocols beyond their accurate indication descriptions would lead to inevitable peri-implant problems and failures. However, long-term randomized clinical trials are still needed to validate the failure risks of these protocols.

3.1.3 Long-Term Postoperative

Prosthesis Related Problems

The cement excess (Fig. 2) has been shown as the most common reason for peri-implant infections [22, 23]. The screw-retained prosthetic restorations, with this respect, have the advantage over cement-retained ones. However, supragingival finishing of crown margins could be advantageous for the removal of cement excess. Clinically it is important to be aware of that it is almost not possible to remove the cement excess around the implant collar area with subgingival margins deeper than 1.5 mm [24]. Removal of excess cement would relieve the irritation symptoms at the early stage. However, when the bone recession has occurred implant surface debridement and decontamination with or without bone reconstruction could be necessary.

Overloading or Lateral Forces

Occlusal forces transferred to the implant create stress as an outcome of strain around the surrounding bone. Therefore, single implant supported crown extensions simply increase the failure risk (Fig. 2). The collar area of the implant is more prone to support loads. Similarly, implants are designed to transfer the vertical forces to the bone. However, lateral forces harm counteracts with this system and would apply more stress at the collar area. The implants placed to bruxing patients would be prone to the lateral forces, especially which has overlying crowns with accentuated occlusal anatomy or in tight contact with opposing teeth. When a clinician faces with a bone loss around an implant should check the occlusal structure of the implant-supported crown, its interocclusal relation, contacts with adjacent teeth and grinding habits of the patient besides infection problems. Briefly, clinical crown/implant length ratio should also be kept on the advantage of crown length to minimize occlusal bending forces over implant (Fig. 3).

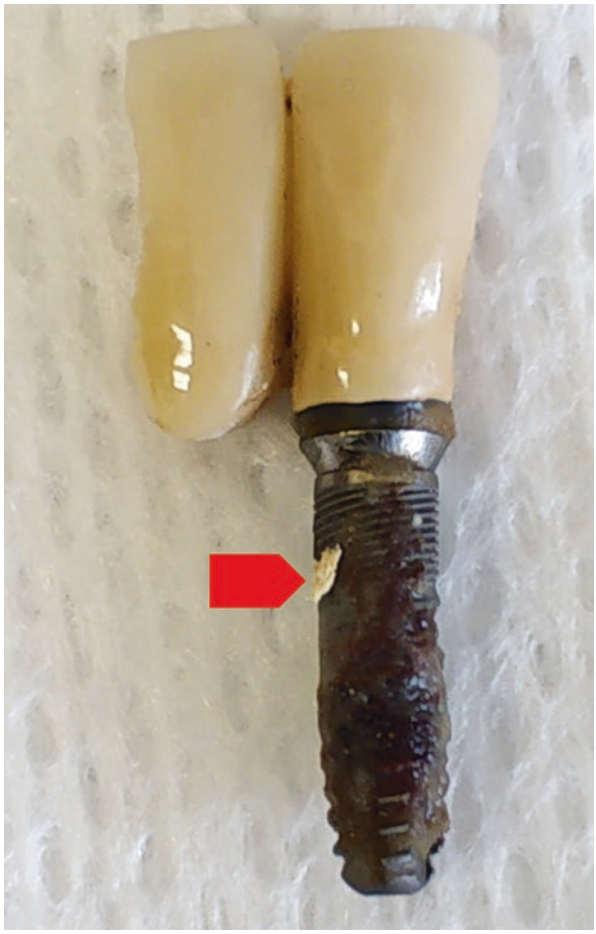


Fig. 2 Excessive cement remnant (shown with red arrow) acts as a foreign body and initiates inflammatory bone resorption around the implant. Additionally, one crown extension on one implant leads overloading of occlusal forces, which leads to periimplant bone resorption

Prosthesis-Related Problems

The cases handed over at the end of osseointegration process for upper structure fabrication can end up with peri-implant diseases in the short or long run. Especially cement-retained fixed dentures are prone to short-term problems due to remaining cement residues at the subgingival area. Those residues would irritate the gingiva and act as a retention area for the biofilm.

3.2 Medications

The bone healing, maturation, and turnover rely on the balance between osteoblastic and osteoclastic activities. The medications, like bisphosphonates, RANKL inhibitors, and thyrokinase inhibitors, are used for osteoporosis treatment and antitumoral

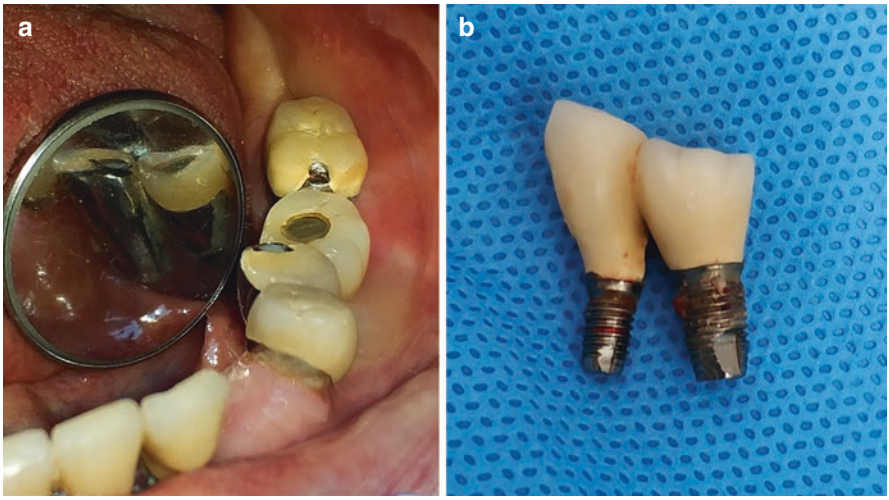


Fig. 3 (**a**) Intraoral view of severely bruxing patient with flattened occlusal anatomy. (**b**) Removed implants demonstrate unbalanced crown/root ratio between porcelain fused metal crown and implant

chemotherapy, and target these bone cycles. The medication-related osteonecrosis of jaw bone (MRONJ) is discussed in another chapter of this book in detail.

Similarly, in addition to these abovementioned chemicals, some of the selective serotonin reuptake inhibitors, like venlafaxine and fluoxetine, in a recent study have been shown to impact bone loss [25, 26]. Moreover, serotonin can inhibit osteoblast differentiation and bone regeneration in rats [27]. Parallel to those findings, preliminary data demonstrate an increased failure rate of osseointegrated implants in patients treated with selective serotonin reuptake inhibitors [28, 29]. The clinical value of this finding is that the clinician should raise a red flag for those patients on selective serotonin reuptake inhibitors as a high risk for implant failures. Similarly, osteoblast inhibition can be seen with some chemotherapeutics, like methotrexate (MTX) and doxorubicin. As the use of MTX has become popular for the treatment of arthritis cases, this patient group is under the suspicion of high risk of implant failure.

3.3 Infection

Infection around an implant presents classical clinical signs and symptoms, like pain, pus discharge, swelling, and erythematous color of the gingivae. When untreated, it easily progresses and causes failure of the implant and moreover can spread to the surrounding tissues.

3.3.1 Intraoperative Contamination

Most possible cause of early peri-implant infections could be via surface contamination with saliva. As a kind of cultivation environment mouth has the highest

variety and account of bacteria, which makes saliva highly contagious medium. Inoculation of bacteria onto the porous implant surface could give a good chance to start up the colonization of microorganisms. With this regard, absolute care and caution should be given to keep the implant surface intact during insertion to its cavity. Either direct saliva exposure or contaminated suction tip or tool contact would end with failure. Experimental studies reveal that contamination of implant with the saliva has an important role in compromising bone implant contact [30]. It is also documented that adherence of the periodontopathic bacteria on titanium and zirconium are not different [31].

To minimize this contamination risk patient's oral hygiene standards must be maximized preoperatively and immediately before the procedure chlorhexidine mouth rinse could help to reduce the density of microorganisms. However, the aseptic technique is a must and maximum caution to avoid saliva contamination during the whole implant insertion procedure.

Secondarily, missing counterparts of aseptic surgical technique can be encountered as another contamination cause of the bone cavity. When the primary work of implant drills is considered, cleaning and decontamination of those drills gain a critical role not only for peri-implantitis occurrence but also cross-infection risk. It has been demonstrated that bone debris can remain on the cannulated orthopedic instruments and cannot be sterilized even by autoclaving [32]. Similarly, among the manual cleaning, immersing, and ultrasonic cleaning, none has shown complete eradication of biologic debris [33]. Even the mechanical debris is eliminated, protein remnants on the metal surface can sustain after cleaning of surgical drills [34].

3.3.2 Increased Surgery Time

Well-known conventional surgical standards mandate to minimize the surgery time to reduce infection risk. This understanding should be regarded with dental implant placement procedure as well.

3.3.3 Lack or Loss of Keratinized Gingiva

Presence of 3 mm length of keratinized attached gingiva around the restored implant is required. High soft tissue attachments to the marginal gingiva of the implant would lead bone recession due to pulling-effect of soft tissue towards the apical direction. During the healing period of single stage or double stage implants lack of keratinized attached gingiva should be restored with soft tissue grafting, before the prosthetic restoration.

3.3.4 Experience of Surgeon

As presented in the previous two topics, clinical skill of the surgeon is also considered one of the surgery-related factors. Besides the fundamental surgical concepts, tissue healing, and osseointegration basics, the clinician must be equipped with implant planning knowledge as well. In addition to atraumatic tissue handling skills, the clinician must have a compromised understanding on management of complications before attempting implant surgery. Didactic education and hands-on phantom jaw practices should be regarded as basic steps of clinical training. Clinical

shadowing and assisting an experienced surgeon should be considered a part of the implantology training to minimize complications.

3.3.5 Previous Infections: Immediate Placement at an Infected Tooth Socket

Direct inoculation of bacteria to the implant surface in theory is inevitable. However, many studies advocate that survival of implants placed immediately after infected tooth extraction is not different than the ones placed into non-infected tooth extraction sockets. A quality assessment study for these systemic review studies reveals that their methodological quality is low or moderate [35]. Even the studies advocating immediate placement of implant to infected fresh tooth sockets suggest taking measures that minimize loss of hard and soft tissues around implant [36]. Long-term results with good study designs are needed to define limitations of immediate implant placement into infected fresh extraction sockets.

3.3.6 Retrograde (Periapical) Peri-implantitis (Periapical Implant Lesion)

In general, the radiolucent lesions occur following placement of prosthetic restoration at the apical portion of the implant while the rest of the bone presents that natural osseointegration is described as retrograde or apical peri-implantitis. Various names have been used to describe this entity. Overall, besides the radiologic appearance, clinical manifestations are expected.

Etiology of the apical peri-implantitis can be inherited from the preceding lesions of an extracted tooth (odontogenic causes) or originated from non-odontogenic factors (Table 1).

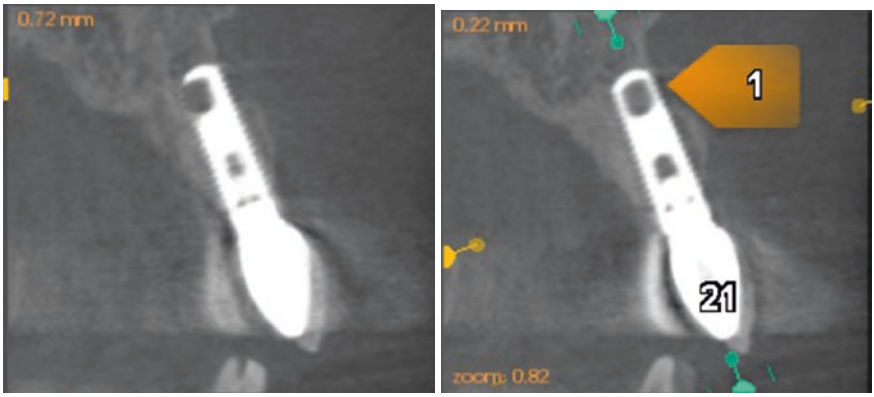
As discussed previously, immediate placement of an implant to fresh extraction socket has its risks. Though, iatrogenic factors can occur shortly after placement of

Table 1 Etiology of retrograde peri-implantitis of endodontic origin, table was adapted from [37]

Odontogenic	Non-odontogenic
Root canal system infection	Implant surface contamination
Extra-radicular infection	Overheating
Extruded root canal filling or other exogenous materials	Surgical drilling beyond the length of the implant
Accumulation of endogenous cholesterol crystals	Fenestration of vestibular bone
True cystic lesions	Bone compression
Scar tissue healing of the lesion	Drainage of inflammation via marrow spaces
Violation of minimal distance from adjacent tooth	Varying bone quantity at apical and marginal areas in cross-sectional view
Residual root particles or foreign bodies	Poor bone quality
	Premature loading
	Development of osteomyelitis
	Technique of the particular system used
	Bone loss caused by mucoperiosteal flap procedure
	Inadequate bone grafting at apical area of implant

implant. Similarly, secondary infections due to hematogenic spread, osteomyelitis, or sinusitis might lead such lesions as well. Those infective diseases, once its origin is identified, should be managed by eliminating the cause and decontamination or removal of the affected part of the implant with or without bone grafting.

On the other side, lack of preoperative radiologic evaluation might deceive the clinician could give an impression after the placement of the implant that there is a lesion at the apical part of the implant. Due to this pitfall, the clinician can simply end up with the surgical exploration of a healthy implant to treat a nonexistent infection. To avoid such deceptions, a preoperative radiologic study should be done with three-dimensional CBCT. However, if this step was skipped and a periapical radiolucency is identified after implant placement before any surgical attempt clinician should confirm the presence of apical lesion with a CBCT besides any clinical manifestation of infection (Fig. 4).



Histopathological examination generally reveals granulation tissue findings (chronic inflammation) and/or cystic structures [37]. Once the diagnosis of retrograde peri-implantitis gains certainty with clinical signs and symptoms and radiologic findings, surgical entry to the periapical site of the implant is necessary. Entire infected implant surface is exposed. If the affected area is approachable with non-surgical debridement and decontamination tools or techniques, it should be treated with non-surgical and surgical regeneration techniques. If the access to the affected area is not possible, implantoplasty should be used to remove the infected part of the implant surface. Up to 1/3 tip of implant length could be removed with high-speed drills under sterile water irrigation unless the crown/root ration would not be disadvantageous for the implant survival (Fig. 5). Following the partial implant tip removal, the bone defect site can be left for healing with guided bone regeneration or bone grafting. However, in cases where the apical implantoplasty can damage the surrounding anatomical structures, like inferior alveolar nerve or maxillary sinus, removal of the implant could be considered in symptomatic cases.

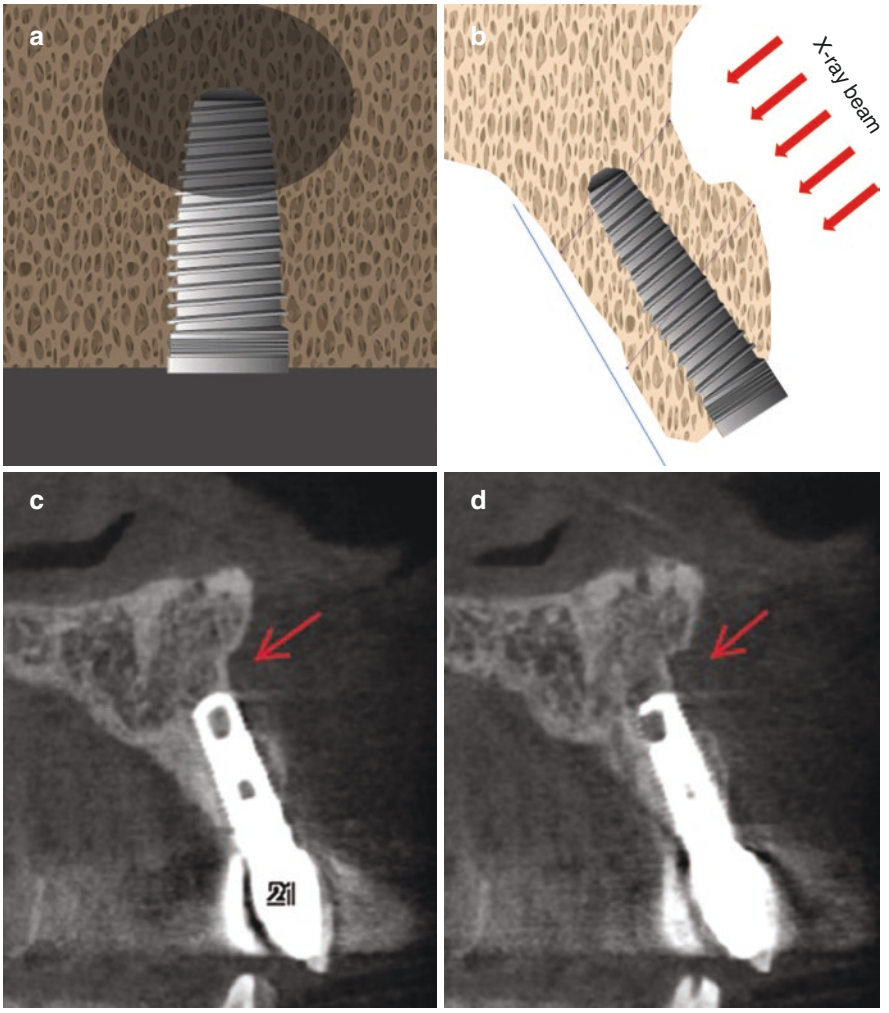


Fig. 4 (**a**) Illustration of a periapical radiolucency around the apical part of implant. (**b**) The periapical radiolucent appearance around the implant at tooth site can be an impression on the alveolar bone surface. (**c**) CBCT scan reveals that the radiolucency is due to a thinning or fenestration of the buccal bone at the periapical site of the asymptomatic implant. (**d**) CBCT slices can also reveal loss of bone to implant contact at some areas as well

3.4 Implant and Sinus Interactions

As the proximity of a periapical infection to the sinus causes sinusitis secondarily, the same pattern of infection transition can be seen between the implant and sinus relation in two ways. The peri-implant infection, if not treated, would advance up to the apical part. In close relation with the sinus cavity, advanced peri-implantitis can initiate mucosal inflammation and lead to maxillary sinusitis secondarily [38, 39]

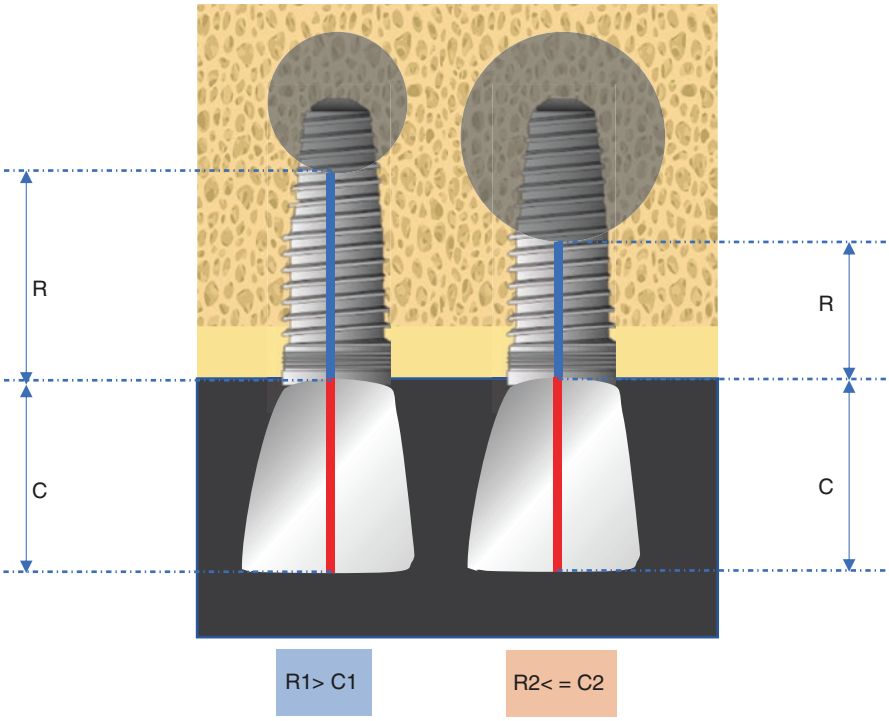


Fig. 5 Apical 1/3 of the implant length can be removed as long as the crown/root ratio allows biomechanically for the treatment of apical (retrograde) peri-implantitis

(Fig. 6). In this case, peri-implantitis treatment modalities those are given at the following part of this chapter should be applied at the first step besides medical sinusitis treatment, like systemic antibiotic use, etc. The progress of sinusitis signs and symptoms must be closely followed up. For those patients who have ongoing sinusitis removal of the infected implant could be necessary before any surgical sinusitis treatment. The implant removal should be considered as the first and only choice for advanced peri-implantitis cases. Persisting sinus infections, even after implant removal, require medical and surgical interventions.

Moreover, oroantral fistula formation along the implant body (Fig. 6) should be considered in such advanced peri-implantitis cases as a secondary complication, which requires surgical sinus closure additionally. Besides, in long-standing cases, with the progressive bone loss, dislocation of the implant into the maxillary sinus can be inevitable. In this condition, the endoscopic sinus intervention or Caldwell Luc procedure can be used to remove the implant from sinus.

Then again, the zygomatic implants, specifically the trans-sinus implants have been shown as peri-implantitis induced sinus infections in several case reports [40–43]. The remedy searches for the management of implant-related sinus infections in such trans-sinus implants indicate the extra-sinus placement of zygoma implants when possible [44]. Even use of bone morphogenic protein-2 and absorbable

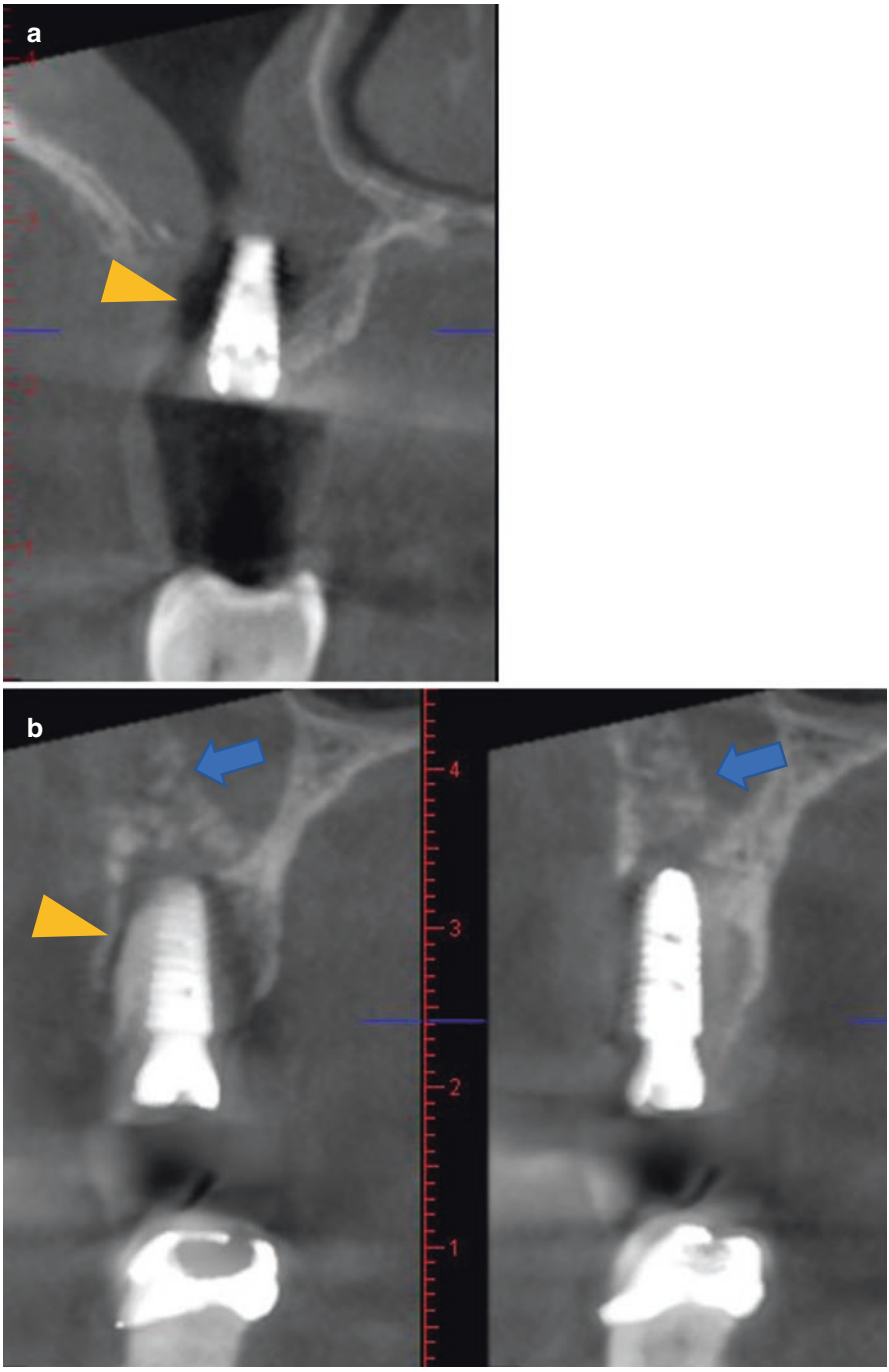


Fig. 6 Cross-sectional CBCT image of maxillary sinus. (**a**) Maxillary sinus mucosa reveals thickening in close relation with dental implant places into the sinus cavity and oroantral fistula along the implant body (yellow arrow tip). (**b**) Other than mucosal thickening and fistula (yellow arrow tip), scattered bone graft particles (blue arrow) can be seen in the sinus cavity

collagen sponge combination has shown to be promising as a measure, without complete debridement and decontamination of a trans-sinus implant, which is beyond the current technical practice and requires further proof with clinical trials.

On the other hand, when the simultaneous implant placement with bone grafting is considered, a secondary infection of bone graft material would eventually be an additional risk for the development of peri-implantitis. It would be an optimistic view that expecting an intact implant in an infected bone graft area and retaining the implant after bone graft debridement could cause recurrent infections. Therefore, elimination of the implant should be encountered while the bone graft is removed [45]. Following the clearance confirmation of sinus infection, sinus floor augmentation and implant placement could be planned in different sessions.

Looking at the sinus–implant-related infections from another perspective is also important for the planning of implant placement at the maxillary posterior area, especially if the bone grafting of the sinus floor is also part of the treatment plan. The presence of maxillary sinusitis is a major factor, which dramatically lowers the survival rate of implants [46]. Therefore, the sinus infection must be eliminated before implant or bone grafting at this area. After the eradication of the sinusitis, patient's clearance should be confirmed with a recent endoscopic examination or computerized tomography [46].

3.4.1 Periodontitis and Peri-Implantitis Relation

There is a remarkable increasing effort to identify the causative microorganisms of peri-implantitis by several study groups. However, most of those trials are observational and descriptive, and there is no consistency between their methodologies. Though, there are common points of those studies, which point out that the peri-implantitis-related microfilm has a variant and mixed population. Other than common members of the oral microbiome [47], peri-implant infection-related microbiome presents nonsaccharolytic anaerobic gram-positive rods, gram-negative anaerobic and opportunistic microorganisms [48]. Also, *Porphyromonas gingivalis, Tannerella forsythia, Treponema denticola, Prevotella intermedia, Fusobacterium nucleatum, Aggregatibacter actinomycetemcomitans, Eikenella corrodens, Parvimonas micra, Campylobacter rectus,* other *Spirochete* spp.*, Bacteroides, Peptostreptococcus, Fusobacterium, Veillonella, Streptococcus spp., Enteric gram-negative rods and yeasts* are shown as commonly identified microbiomes [49–53].

Following the Human Microbiome Project introduction [54], a revolutionary outlook to the microbiome of dental microflora composition has brought a novel dimension for the identification system (Fig. 7) [49, 55]. The new perspective reveals that individual pathogens are not always prominent etiologic agents in peri-implantitis. Moreover, those infections occur due to a shifted balance between natural microflora, host defense, and microenvironment [49]. The dynamic interaction between pathogen bacteria, viruses, and yeasts is primarily linked to this disequilibrium and tends to transform into a pathogenic composition.

Nevertheless, the compositional variations between geographical locations, age and gender groups, systemic health conditions, dietary and oral hygiene habits, even sampling location within the mouth should be regarded to depict a standard

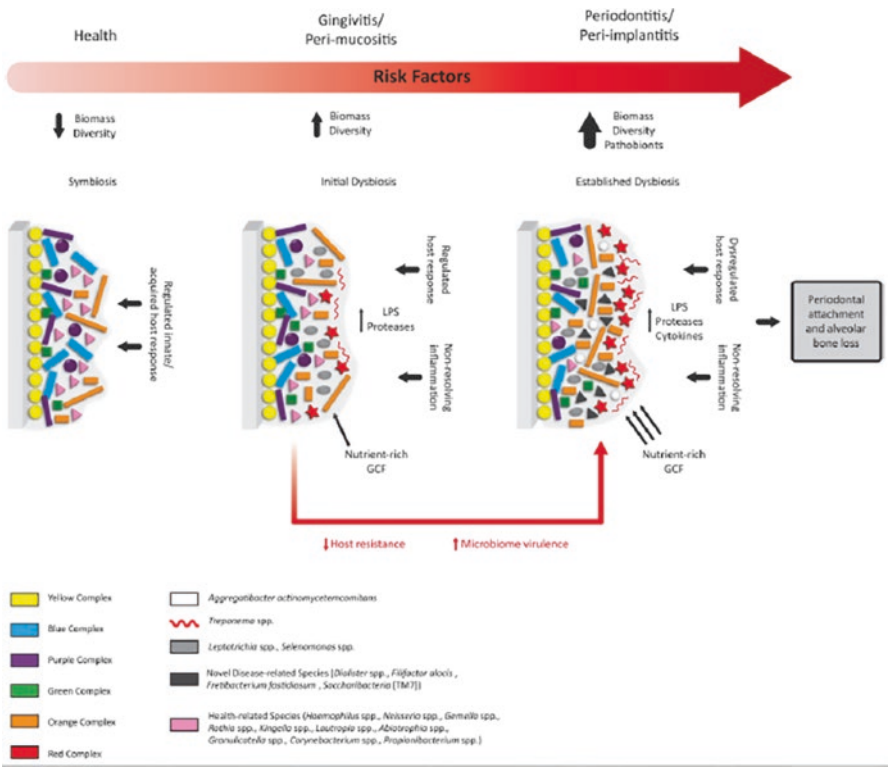


Fig. 7 Predominant microbiomes in different periodontal states. In a healthy periodontium, a low biomass of gingival and subgingival biofilm, comprised mainly of symbionts, is controlled by an efficient and self-limiting host response. Biofilm accumulation leads to increased but self-limited chronic inflammation that favors the emergence of periodontal pathogenic microorganisms, including members of the orange and red complexes [56]. Depending on host susceptibility and the presence of various risk factors, a complex pathogenic periodontal microbiota composed of high proportions of putative and novel pathogens is established. This dysbiotic microbiota promotes a dysregulated immune/inflammatory response that will result in loss of periodontal supporting tissues. *GCF* gingival crevicular fluid, *LPS* lipopolysaccharide

microflora for peri-implant infections. Therefore, an empiric antimicrobial therapy regime can be suggested on a case base.

Interestingly, current trials reveal that there is a noticeable increase in viral spices in the peri-implantitis microbiome. The presence of human herpesviruses, Epstein–Barr virus, human cytomegalovirus, and herpes simplex virus is a noticeable variation in implant-related infections [48, 57–59]. Even those clinical trials have no heterogeneity and are limited to small populations when the varying distribution of microbiome is regarded, shifting from normal flora to the opportunistic microbiome can be depicted. This drift could explain the initiation of these infections. The clinical weight of this value is enough to raise the expectation of a higher peri-implantitis incidence in immunocompromised patients.

So far, the zirconia as an abutment material has offered superior esthetic and gingival healing advantages over titanium. As a dental implant material, it might have a potential in the future; however, further clinical trials are needed [60]. Nevertheless, the biofilm formation on titanium and zirconium oxide surfaces is still a discussion point [61, 62]. Due to the lack of long-term studies, the zirconia has no proven advantage or disadvantage over titanium implants regarding peri-implant infection risk.

Even the lack of standardization among the studies and some weaknesses of their designs could be pointed out, correlation between periodontitis and peri-implantitis has already been shown homogenously with several meta-analysis studies [63–67]. Despite the differences between periodontitis and peri-implantitis pathogens, the common microorganisms should be regarded. The value of this correlation can be used in clinical practice as a predictive factor that can guide the clinician while making the treatment planning and organizing the follow-up schedule for this patient group. The history of periodontitis can be a remark for the clinician to initiate basic, and if necessary advanced, treatments, which should be completed before any implant planning.

Similarly, frequent oral hygiene checks are advised to be done to improve the maintenance for this patient group to minimize the implant failures, so that increased periodontal pathogen populations and negligence-related implant failure risks could be hold under control.

The clinician can consider that the supramarginal finishing of the crowns out of esthetic zone might help to maintain the cleaning correspondingly, following implant placement clinical follow-ups could be scheduled more frequently than a healthy patient agenda. Based on this result, even informed consent modification can be considered for those implant candidates who have periodontitis history due to higher peri-implantitis risk.

To minimize the contamination risk and failure risk of implant perioperative use of antiseptic mouthwashes like chlorhexidine is suggested only in a limited amount of studies [68, 69]. In daily practice, the practitioner can simply use a single preoperative mouth rinse to decrease the count of microorganisms in the saliva to reduce contamination risk. In the same manner, postoperative use of chlorhexidine rinse not more than one week might reduce wound site infection risks without creating any harm other than discoloration of the teeth and oral mucosa.

Use of antibiotic prophylaxis during the perioperative period of implant placement has been a discussion point of several groups. While some research groups show the benefits of perioperative antibiotic use [70–73], the contrary group defines it as not necessary with their results [74–76]. When regarding the use of antibiotics has some risks like allergy and side-effects, its routine use should be avoided in healthy patients [77]. However, unfortunately, during the daily practice the clinicians still administer a single dose preoperatively or prescribe antibiotics postoperatively for implant placement procedure [78–83]. It should also be regarded that the antimicrobial agents could only be in effect at the beginning of the wound healing process and might play a role in the early wound infections. Even if they influence implant failure, it is limited to early failures. However, long-term failure of the

implants can generally be attributed to lack of oral maintenance or denture-related issues, etc. Though antibiotic prophylaxis does not offer any major benefit, if the practitioner is still insisting to use it, should at least follow the WHO guidelines by prescribing the first line of antibiotic [77] perioperatively. With this regard local regulatory guidelines are necessary.

3.4.2 Spread of Adjacent Infection to Implant

During the implant planning, the condition of the adjacent teeth should also be evaluated, and any present periapical or periodontal pathologies should be cleared before the implant placement. Otherwise, periapical (retrograde) peri-implantitis of the implants secondary to the adjacent tooth infection is inevitable due to the direct spread (Fig. 8) [84–86]. For the resolution of such secondary involvement, elimination of the primary cause besides the peri-implantitis treatment protocol should be followed. Though, idiopathic periapical radiolucent appearances should be assessed preoperatively in detail concerning any possible bony topography deformities. The CBCT can be the best assessment tool to evaluate intraosseous lesions and possible morphologic deformities.

3.4.3 Bur Cleaning

Cross-contamination-related peri-implant infections via reused surgical drills have been a concern. Remnants of bone debris on the cannulated orthopedic instruments have shown to diminish the efficacy of the sterilization process [32]. Likewise, tissue remnants possibly remain after reprocessing of especially on internally cooled bone drills is expected to increase cross-contamination risk. Regarding the drill reprocessing and implant infection relations, there is only one study in the literature, which reveals that using the hygienic procedure routinely used in dental practice, pre-cleaning disinfection, internally cooled drills can be successfully disinfected.

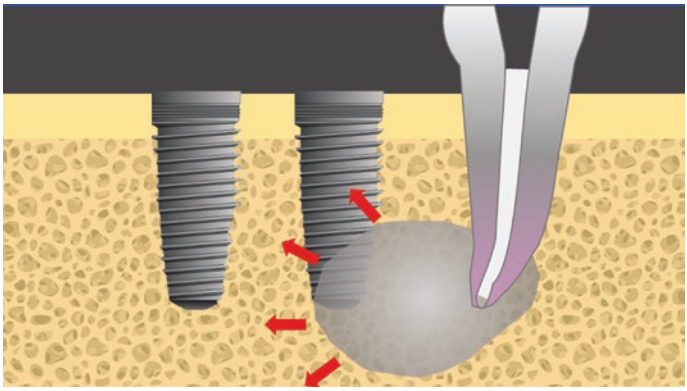


Fig. 8 Diagrammatic illustration of the possible spread of any periapical lesion from an adjacent tooth to the neighboring implant. In the opposite direction, periimplant lesions could spread to the adjacent teeth

Also, ultrasonic cleaning can provide more effective debris removal than hand cleaning [87].

The adhesion of some specific microorganisms is less likely on polished drill surfaces [88]. Particularly following several drillings, chemical, and ultrasonic cleaning and autoclaving cycles, roughness on the drill surface could allow adhesion of biodebris on the drills. Therefore, renewal of the implant drills after certain cycles is necessary, as advised by many producers.

3.4.4 Perioperative Antimicrobial Agent Use

To reduce the postoperative infection risk, perioperative use of antimicrobial agents has been at the focus of many studies. Owing to the fact that the use of chlorhexidine and povidone-iodine mouth-solutions has a positive impact to reduce the microorganism population in the oral cavity [89, 90], single use of these as a mouth rinse can be suggested because of their efficacy and potential to reduce implant failure risk [89, 91]. Particularly, when the relation of peri-implant infections with biofilm accumulation of the implant surface is considered, postoperative rinsing regimes can also be suggested to a certain extent. So far, there is no controlled clinical trial proving the benefit of this application. However, when the proven antiseptic efficacy of chlorhexidine is regarded, also as a general surgical rule, preoperative single use of chlorhexidine can be beneficial to reduce microorganism count in saliva and reduce early infection risk.

On the other hand, use of prophylactic antibiotic to reduce implant failure risk is another controversial subject, which has not been clarified with any major scaled controlled clinical trial [74, 92, 93]. Beyond the consensus between users and non-users, yet there is no agreement even for which antibiotic protocol should be used [72]. Moreover, negative outcomes of misuse of antibiotics have been described by the World Health Organization [77]. Though this dispute and documented possible risks of antibiotic use for prophylaxis, in daily practice most of the practitioners do prefer to prescribe prophylactic antibiotics to reduce the failure risk of the implants [78–81, 83, 94, 95]. Possibly it is caused by the concern of the practitioner to minimize implant losses due to early wound infection risk. Hence, more clinical evidence is needed to verify the benefit of perioperative antibiotic use on long-term success. Also, local regulations can restrict this practice for those patients who need prophylaxis.

3.4.5 Lack of Postoperative Follow-Up

Even the literature does not have long-term results concerning postop follow-up necessity, clinically early detection of any disease is necessary for the sake of the progress of the treatment. Specifically, when the reversible nature of peri-implant mucositis is regarded practitioner must be vigilant and keep the implant patient under control [96]. One of the major factors on implant failures is the lack of follow-up after implant placement or restoration. It is critical to evaluate and interfere the oral maintenance deficits, but also to assess prosthetic restoration functionality and overloading [97, 98]. Over a mean period of 6-year follow-up is generally a proper time and minimum twice a year in a healthy patient is strictly suggested to avoid

peri-implantitis problems [98–100]. When the clinician has any concern about hygiene maintenance or systemic condition, like diabetes, etc., of the patient the follow-up period could be shorter than the suggested time until the condition gets under control.

3.4.6 Micro Gap Between Implant and Abutment as a Bacteria Resource

The studies arguing the implant-abutment interface as a colonization area [101] due to the lack of standardization to compare the study results [102] and its importance in clinical practice are still unclear and require further evidence. However, though such studies indicate the micro gap between implant and abutment as a possible cultivation area which might predispose peri-implantitis [103], biomechanical effect of screw loosening due to this gap should be regarded as a higher risk value for peri-implant bone losses [104, 105]. This gap should also be considered as the cause of micromovement of the abutment, which leads the fatigue-related screw and implant fractures.

3.4.7 Peri-implant Graft Related Risk

Reconstruction of mandibular or maxillary bone defects requires bone and soft tissue grafting. As a graft material, each has an additional morbidity risk, like rejection, necrosis, or infection, which jeopardize the survival of dental implants. Strategically, the placement of the implants would follow the healing of the graft material to minimize graft-related implant losses. On the other hand, the peri-implantitis risk at skin grafted intraoral sites is higher. Its cause has shown to be increased microbial load instead of different microflora [106]. Besides this elevated infection risk, the restricted access of toothbrush to the implant abutments due to contracture formation at the soft tissues could contribute to raising the peri-implant infections. Patient education about mechanical oral hygiene maintenance and frequent clinical follow-ups would assist the clinician to keep the infection risk at the minimum level.

In the clinical practice, use of iliac bone grafts for the reconstruction of jaw defects or severely atrophied jawbone is the first line grafting. Their long-term outcomes with implant restoration are predictable [107–109]. However, other than one report, which reveals two failed out of 52 implants placed at bone grafted area following mandibulectomy [110], there is no paper assessing the risk of peri-implantitis at bone grafted areas probably due to the difficulty to have long-term follow-up on patient population with malignancy. In addition to those shortcomings, other confounding factors like systemic diseases, radiotherapy, and major shifting of digestion as well as the microflora in this population should be considered as some of the reasons about such long-term studies. Especially, the compromised vascular supply of the area in irradiated jaws should be considered as one of the major causes of implant failures [111].

Bone grafting of major bone defects might follow radiotherapy to the head and neck area after resection surgery. As the compromised vascular supply after radiation, the vascularized free fibula graft has become popular due to higher perfusion

possibility comparing to non-vascularized bone grafts and the implant-supported dentures are shown to be reliable and predictable [112]. However, in the long run, peri-implant bone resorption occurs and would lead failures in oncology patients reconstructed with a fibula free flap. The reason for this failure issue is indicated as mainly related to peri-implant gingival mucositis. As a solution skin or connective tissue grafts are suggested to offer aid to manage this problem [111].

3.4.8 Structure of Implant

The dental implant is structured for maximum bioavailability, good integration, minimal bacterial adherence, but maximum stress distribution where it is placed. Today's implants have taken their current shapes and structures after a long evolution period full of failures. The clinician should realize that each design of ultrastructure offers different advantages and deficits, for which he or she should pick the right one for each case or even for each location. However, yet there is no adequate evidence showing the relation of peri-implantitis with surface characteristics of the implant [113]. As the detailed information is given biomechanics of implant design and surface texture and coatings, the author would like to address this title as a possible reason for bone loss around the implant. To diminish the bacterial adhesion, sulcular and intraoral parts of the implant are produced with polished surfaces while the intraosseous part is roughened to maximize osseointegration. The practitioner should realize that as the tissue recession extends beyond the polished collar area the biofilm accumulation would dramatically increase on the roughened implant surface, and an adequate plaque control cannot be done. As a natural outcome, the progress of peri-implant infections would be faster unless the required measures are taken.

3.4.9 Genetic Tendency

The genetic predisposition for peri-implant diseases likewise in any genetic disorder could be classified into three categories, which may contribute the pathology separately or in combination as (a) immune function, (b) bone growth, and (c) regulation of gene expression [114]. Yet, as the current studies show a wide variation between their designs and were conducted on small population samples, no strong evidence could be drawn. However, in specific patient populations with a genetic predisposition to immune system deficiencies, higher incidence of peri-implant infections should be considered and related measures like oral hygiene training, long-term follow-up, or hygienic prosthetic designs must be practiced.

3.4.10 Systemic Condition of the Patient

Similarly, to genetic tendencies, the implant candidate with diabetes, xerostomia, smoking, alcoholism, malnutrition, drug addiction, cancers that can affect immune system (lymphomas, leukemias, multiple myeloma), radiotherapy, MRONJ, Paget disease, fibrous dysplasia, or syndromes like Ehlers–Danlos syndrome should be regarded as a high peri-implant infection risk group.

The patient group with human immunodeficiency virus (HIV) infection may have a higher incidence of peri-implant infections in the first six months. This

patient population can be suitable for implant placement if the systemic condition is under control and with well-maintained oral hygiene. Even though, long-term success rate for implants can be lower than healthy patient population [115].

As discussed in the related chapter, control of the underlying systemic factor should be prioritized before implant surgery. For the patients with an uncontrolled systemic factor, implant placement would likely end up with early or long-term failures [116].

4 Diagnosis and Treatment Planning

While investigating a peri-implant disease, initial attempts should be given to search and eliminate any possible predisposing local and systemic factors for peri-implant bone loss. As described in the previous section, implant and surrounding structures should be assessed in detail for any interactive relation. In general terms, peri-implant mucositis is a reversible inflammatory condition, which is limited to the gingival tissue. However, as the inflammation extends to the connective tissue and bone (roughened surface of the implant), it is named as peri-implantitis and characterized with marginal bone loss. This irreversible inflammatory process has a non-linear and accelerating pattern [117].

The description of success criteria was defined as the bone-implant interface by Alberktsson et al. [118]. However, the stock point of recent patient-centered studies reveals that the success measure of implant has been shifted on implant level, peri-implant soft tissue, prosthesis, and patient's subjective evaluation [119]. Increased attention on the long-term implant success also revealed that other than implant material and design, there are equally valid or more dominant factors affecting the marginal bone loss (MBL). Following the evolution of the implant material and design choices to reduce implant-related issues, the contemporary implant systems on the market have similar long-term clinical success with respect to MBL and failure rates [120].

4.1 Clinical Findings

According to the new perspective, to evaluate peri-implant tissue condition, patient's chief complains, the progress history has critical value. Notably, the presence of pain or tenderness at the implant site is not as simple as in dental pain. The origin of the pain should be searched and identified. If its relationship with an implant is verified, the investigation must be deepened by controlling other signs and symptoms. Within the first week of placement, some mild to moderate tenderness is normal at the implant site. Due to excessive flap traction during surgery or placement of any bone graft material can end up some increased tenderness during the early stage of the wound site. Any sensitivity at the implant site after healing is not expected.

Nevertheless, if present any possible ill-fitting dentures or denture parts should be controlled as the cause of this sensitivity. Implant percussion or occlusal forces over 500 g can be used to check the tenderness. A mild sensitivity at the implant area while

biting, can direct the clinician to consider the salvage procedures. However, severe pain with pus discharge is a good indicator of the failure, and the implant can be removed.

Similarly, the mobility is another clinical finding, on which most of the studies agree and described as a red flag for a failure. Due to the difficulty to make a precise numeric measurement of the mobility, the clinician should cautiously identify the source of mobility. All implant-supported mobile crowns should not be tagged as peri-implantitis. Initially, the integrity and stability of implant-abutment fixation screw must be checked for fracture or loosening possibility. Therefore, retrievability of the implant is possible with screw-retained upper structures. The mobility of the implant body indicates complete lack of bone-implant connection and necessitates the removal of implant [121].

Typically, the ISQ value is used to assess the primary stability of the implant before loading, especially it could be useful for immediate loading. When MBL is a concern, primarily to diagnose peri-implantitis, ISQ can be a valuable tool to document the progressive MBL, but not as a diagnostic tool [122]. Yao at al [123]. showed that ISQ values effectively detect narrow, intrabony marginal bone defects, in particular when involving the first coronal 2 mm. In daily practice, a progressive decrease of ISQ value can have a specific value for the early diagnosis MBL. However, ISQ value can never be the only criteria to diagnose MBL but can support other clinical or radiologic findings. Further clinical studies are needed to validate the place of ISQ value in implant stability assessment for peri-implant bone losses.

The presence of other local signs and symptoms should be identified clearly and can be a supporting factor in decision-making or follow-up criteria. Opposite to the periodontitis, where the depth of the periodontal probing has a vital role in determining the severity of the disease, increased pocket depths around an implant do not indicate disease always. It has shown that following the placement of implant approximately 1.5 mm of bone loss can be predicted at the end the first year and a 0.13 mm as an average in subsequent years. As a result, the clinician can use MBL value to observe physiologic bone recession over the years. However, a progressive MBL can be an indicator of a peri-implant destruction, caused by overloading, infection or implant structure failure etc. [3]. Also, the condition of implant-supported restoration should be evaluated for any possible culprit factor.

Correspondingly, the radiologic evidence of MBL with the standardized bitewing or periapical roentgenographs can have a significant value to assess the progress of MBL over time. The MBL beyond the predicted values or progressive losses is an indicator of peri-implant disease. In that case, the clinical findings can aid to define the origin of the issue. Each possible factor, the infection or overloading, etc. causing MBL should be tested and ruled out.

The status of oral maintenance-plaque and/or calculus deposits is one of the best indicators of any possible gingival inflammation likewise in tooth-related gingivitis example. During the clinical follow-ups, any biofilm or calculus deposition on the implant-supported prosthesis or implant neck is an alarm signal for the clinician to interfere with the peri-implant mucositis development timely. Presence of a biofilm accumulation around the implant with any associating clinical findings can help the clinician to diagnose peri-implantitis or peri-implant mucositis. Therefore, implant

maintenance recalls are advised to be more frequent than regular dental check-ups. The biodebris deposition alone is essential to weigh the risk of peri-implant infection but cannot be a single value to diagnose a peri-implant disease.

On the contrary, any change in the status of the gingiva, like bleeding on probing and bright red color, is an indicative finding for the presence of peri-implant mucositis at least. Further investigations like possible increased probing depth, mobility, or radiographic evidence of MBL should be carried out to rule out peri-implantitis.

4.2 Imaging

The routine radiologic evaluation of bone around the implant is usually followed up with serial bite-wings or standardized periapical X-rays with high sensitivity. To track the MBL with standardized images with minimal alterations and with high precision acrylic resin occlusal registrations can give a reliable result. As a bite-wing image can provide more standardized images comparing to periapical images, it might be practical to follow MBL around the implant at first sight. When the occlusal registrations are used, periapical radiographs are more advantageous over bite-wings for advanced bone losses, which extends beyond the bite-wing borders. Measuring the MBL progress with this standardized occlusal registration can be confirmed with MBL amount with implant height proportion (Fig. 9).

However, MBL on the buccal or lingual aspect of the implant can be a pitfall to detect by these conventional imaging techniques. CBCT evaluation can be considered when an increased pocket depth on buccal or lingual sides or buccolingual

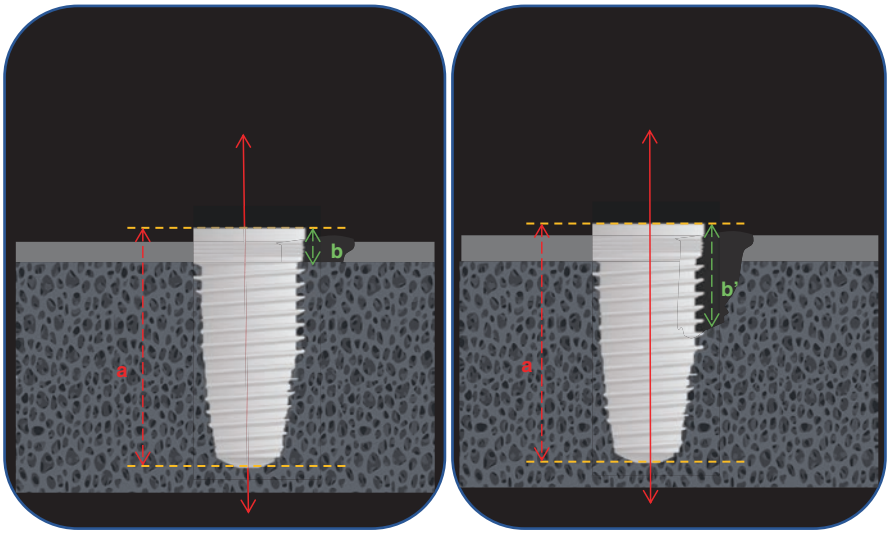


Fig. 9 Illustration of measurement of marginal bone loss around an implant. For this purpose on standardized periapical X-rays, the real length of implant long axis to its length on the image is proportionally compared to the bone defect depth measured on the X-ray image

movement of the implant is detected. Mainly when a periapical radiolucency appearance is noted on the periapical radiographs, before obtaining the CBCT imaging, parallactic periapical radiography technique must be used to rule out superpositioning of any anatomic structure, like an incisive canal or mental foramen. Even periapical radiograph has a high diagnostic value to detect peri-implant bone defects [124], it is limited to interproximal areas. CBCT, comparing to conventional periapical radiograph, has a higher sensitivity to detect bone defects [125]. Especially, when the buccal or lingual MBL possibility is a concern, CBCT is a reliable and cost-effective imaging technique comparing to functional imaging techniques [126].

4.3 History

When a peri-implant infection suspicion is regarded, history of a previous infection at the implant site before placement must be questioned in detail. Particularly immediate placement of implants to fresh extraction sockets could have a higher chance to present an infectious episode around the implant when the possibility of improper debridement of a periapical infection after extraction is regarded. Likewise, if the patient describes a chronic sinusitis history prior to implant placement at the posterior maxillary area, development of a peri-implant infection related with recurring sinusitis could be expected, especially if there is a sinus lifting history on that side.

Any possible predisposing systemic diseases or medications must be reassessed by updating the patient's medical history. If the patient presents a recent development in medical history, implant-supported prosthesis can be taken out of occlusion until the condition is taken under control. Due to the retrievability feature, screw-retained prosthesis has an advantage over cement-retained crowns.

Similarly, patient's habits like bruxing, etc. must also be updated. As the clinician identifies any lousy habit, should eliminate the hazardous effect by minimizing the occlusal forces. For patients who are heavily clenching or grinding, botulinum toxin use on the masticatory muscles can provide a relief of the factor. Simultaneously use of a night guard should also be considered besides the occlusal adjustments of the crown.

5 Treatment of Peri-implant Infections

Besides evaluation and eradication of contributing factors such as denture-related problems, bruxism, and systemic diseases, the practitioner should focus on the management of peri-implant infections. Treatment of peri-implantitis aims to stop infectious progression, reconstruct missing bone volume, achieve reosseointegration, and optimize peri-implant hard and soft tissue recession.

The first phase is the exposure of the infected implant surface. The clinician should evaluate the site and amount of tissue loss initially. The need for regenerative techniques must be clearly defined before the surgical procedure. To make the

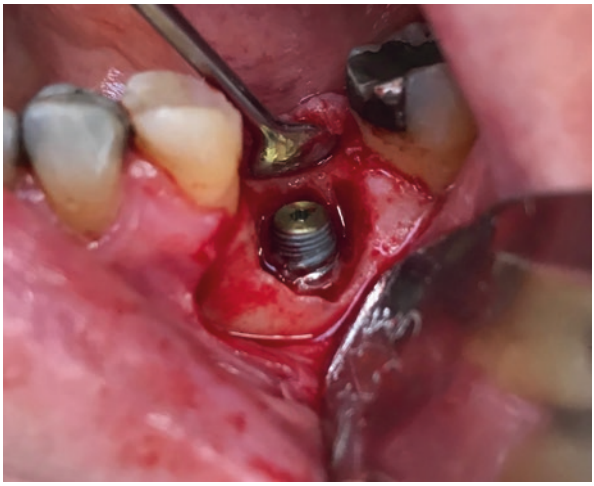


Fig. 10 Intraoral photograph reveals exposure of the implant from buccal and lingual aspects with mucoperiosteal flap

proper flap design, when a regenerative technique is required, the incision can be extended one tooth more in mesial and distal directions and a more extensive flap base must be preferred. Broadened flap design will allow the surgeon to cover the regenerative material and improve the flap perfusion. Atraumatic preparation of a mucoperiosteal flap is necessary to access the bone and implant surfaces. The bone defects extending to lingual/palatal aspect of the implant necessitate elevation of the mucoperiosteal flap from the lingual/palatal side as well (Fig. 10), so that infected surfaces can be approachable.

Since the biofilm development is the cause of those infection-related peri-implant tissue inflammation and recessions, the management strategy should be planned in two parts.

Debridement of the granulation tissue and the biofilm from the implant surface are the following steps. The infected bone surface is also debrided with hand instruments. Then to minimize recurrence risk, decontamination of the implant surface with non-surgical approaches is the following stage. Finally, the reconstructive-surgical techniques can be used to reconstruct the missing hard or soft tissue. In most cases, combination of non-surgical and surgical techniques are needed [1, 127].

Peri-implant mucositis management can be obtained with the removal of biofilm and, if available calculus deposits, with hand scalers or ultrasonic polymer-based tips. Following strict oral hygiene instructions should be provided, with or without chlorhexidine mouth-rinse use for one week [128]. This patient group should be recalled more frequent than healthy ones, due to any possible oral hygiene negligence.

6 Non-surgical Techniques: Surface Decontamination

So far, various methods are used efficiently to remove the biofilm from the implant surface. However, it should be well understood that the removal of biofilm or deposits from the root surface and an implant surface has different aspects. While

removing the biodebris from the root surface, removal of necrotic cement tissue is also achieved. On the other side, while working on a rough titanium surface, clinician aims to minimize the surface structure during this removal process.

Additionally, decontamination is another critical step, which is vital for the success of the bone grafting, reosseointegration of the treated implant surface, and recurrence of the peri-implant disease. Hence the practitioner should be aware of the risks and benefits of each technique and choosing the proper one for the treatment plan. With this regard, the biodebris removal techniques are explained under the following titles.

6.1 Mechanical Debridement

6.1.1 Hand Scalers

Removal of biofilm from the implant surface is the first step of peri-implant infection treatment. With this purpose, mechanical debridement of the implant surface with hand scalers has been in interest since the beginning of peri-implantitis treatment attempts [129], and still a favorite for some practitioners [130]. Various materials, like plastic, Teflon, carbon fiber, and titanium (Fig. 11), have been used as the hand instrument-scaler to minimize the damage to the ultrastructure of the implant surface.

The plastic (Fig. 12a) and Teflon hand scalers cause less deformation on the implant surface [121, 132, 133], while titanium scalers cause deep scratches on the implant surface, which contributes bacterial attachment due to roughened surface [134]. However, early failures after scaling with Teflon instrument can be expected [133].

Ultrasonic Scalers

Ultrasonic scaling with titanium, Teflon, or plastic tips is suggested as a useful tool for peri-implantitis treatment [135]. Though, when the rough surface of dental implant is regarded, after a surface debridement we should expect remaining plastic or titanium residues of the scaler on the porous implant surface [136, 137]. Moreover, eradication of biodebris from the rough surface of a dental implant might not be possible only with mechanical debridement methods [138]. When all these downsides of mechanical removal options are regarded, other decontamination techniques can be considered to have superior effects.

The ultrasonic scalers are used with an irrigation system to minimize thermal damage risk. The power setting of the system should be set to a minimum during the ultrasonic tip use. The smooth scaler tip movements on the implant surface should be applied with gentle pressure (Figs. 12b and 13). The disposable polymer-based tips are generally provided minimal surface damage, however, cannot remove hard calculus deposits. With this regard, Teflon or titanium scaler tips can be more efficient to remove hard deposits, but more structural damage on the implant surface should be expected. Intermittent surface irrigations with sterile isotonic saline should be used to splash remaining debris from the surface and provide additional cooling.

Fig. 11 Titanium hand scaler (Hu Friedy)

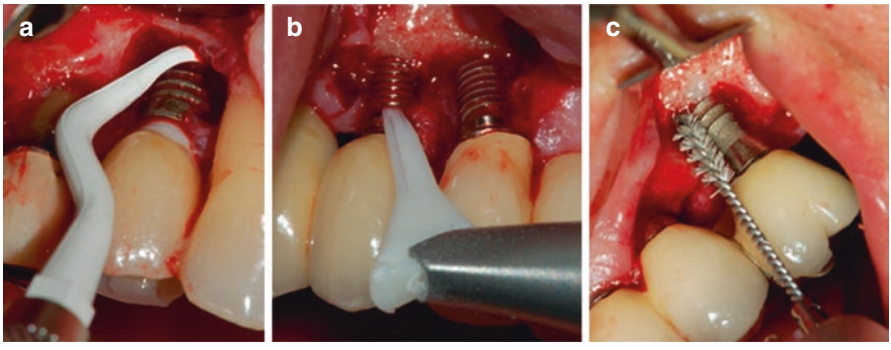


Fig. 12 (**a**) Intraoral photograph showing the use of plastic hand scaler on the implant surface debridement manually. (**b**) Perio-Flow® device. (**c**) Ti-Brush®. Images were taken after the full-thickness elevation of a mucoperiosteal flap and granulation tissue removal [131]

Fig. 13 Ultrasonic scaler with disposable plastic tip enables to minimize damage of titanium abutment surface or collar area while removing deposits (https://www.dentsplysirona.com/en-ca/products/preventive/ultrasonic-scaling/inserts.html/Preventive/Ultrasonic-Scaling/Inserts/Implant/Cavitron-SofTip/p/DET-90411/c/32.html)

6.1.2 Air Pressured Abrasive Powder

Then again, the use of air abrasive powder systems can be suggested for the removal of biofilm from the implant surface. Even improved cleaning efficacy comparing to conventional hand instruments has been shown [138], there is a trade-off between cleaning efficacy and surface damage with sodium bicarbonate powder [139]. Generally, air pressured powder systems, comparing to hand or ultrasonic scalers, can provide superior surface decontamination results with minimal ultrastructural changes on the implant [140]. Additionally, as previously given with the hand instrument example, material residues on the implant surface should also be expected with air abrasive powder systems. Hence, use of calcium hydroxyapatite and biomimetic calcium phosphate particles, which are also osteoconductive materials, as the powder material of the air abrasive system can take place in the clinical practice due to successful removal efficacy of calcified biofilm remnants from the titanium surface [141].

Similarly, recent experimental studies focus on the type of powder material used for surface decontamination. Sodium bicarbonate, glycine, erythritol/chlorhexidine, and tricalcium phosphate or their combinations are used for this purpose [139, 142, 143]. Combination of glycine and tricalcium phosphate can provide more effective debridement outcomes on zirconium-based implant surfaces [142]. Thus, in theory, remnants of biocompatible particles could help re-osteointegration of the treated implant surface.

For the application of the air pressured powder onto the implant surface, a special nozzle is used in non-contact mode. The tip should be aimed parallel to the implant grooves (Fig. 14) and moved from coronal to apical direction with circular movements for 5 s. A high-volume suction (HVS) at 50 mm away from the nozzle is advised to reduce the distribution of debris splashes departed from implant surface, which could lead inoculation of the biofilm into the surrounding healthy tissues. Also, powder deposits can be minimized with HVS. As a general rule, the air pressure greater than 15 pounds per square inch use on tissue should be avoided to eliminate possible emphysema risk [144].

6.1.3 Rotating Brush

As one of the mechanical debridement systems, the rotary metal brush has been shown as a useful tool to remove the biodebris from the implant surface. So far

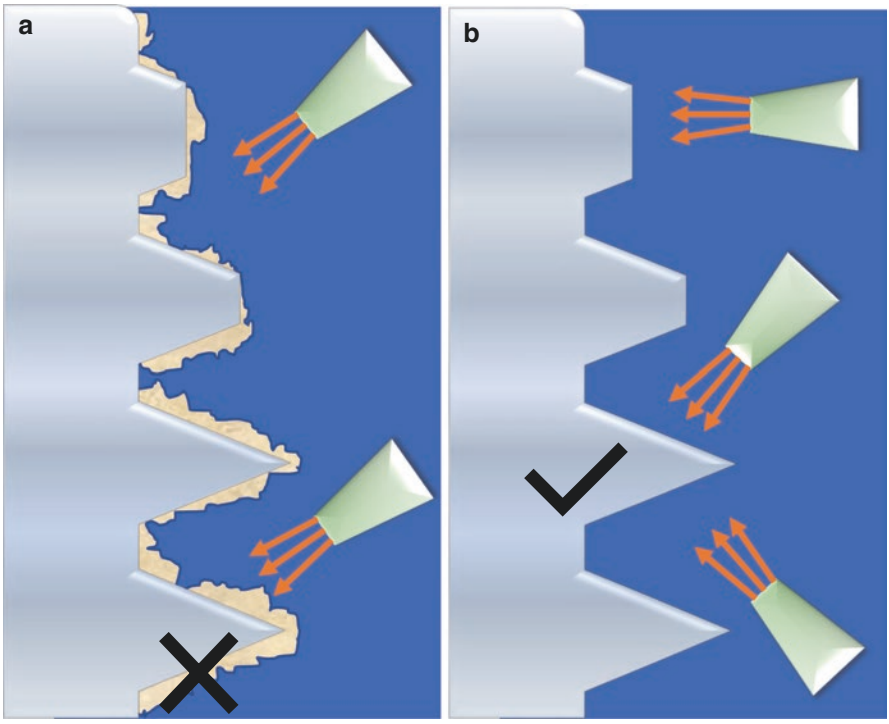


Fig. 14 Schematic illustration demonstrates use of air-flow tip. (**a**) Tip is aimed only in one direction, which may not provide efficient elimination of the biofilm from the implant grooves. (**b**) Multidirectional aiming of the beam can reach all aspects of groove curves

stainless steel, titanium and nylon brush use appear to be suitable for the debridement. Still, likewise, in other mechanic debridement tools, remnants of the debriding tool material on the implant surface should also be considered with this system as well.

Owing to the possibility that remnants of the brush material could remain on the implant surface, titanium brush has an advantage over the other alternatives. Some recent trials show that the titanium brush with glycine air-polishing system can provide more effective debridement than the other mechanical methods; however, its clinical outcome would be the same [131].

The titanium bristles originate from a stainless-steel shaft to be used with a low-speed surgical handpiece (Fig. 15). The exposed implant surface is debrided with 800–900 RPM speed in two directions (clockwise and counterclockwise) for 30 s. During the surface treatment to avoid thermal damage due to frictional forces, the working site should be irrigated with copious isotonic saline solution. Moreover, additional cooling flash should be administered to lower the temperature after brush application. Use of a high-volume suction can be considered to minimize scattering of biofilm and titanium particles into the surrounding healthy tissues.

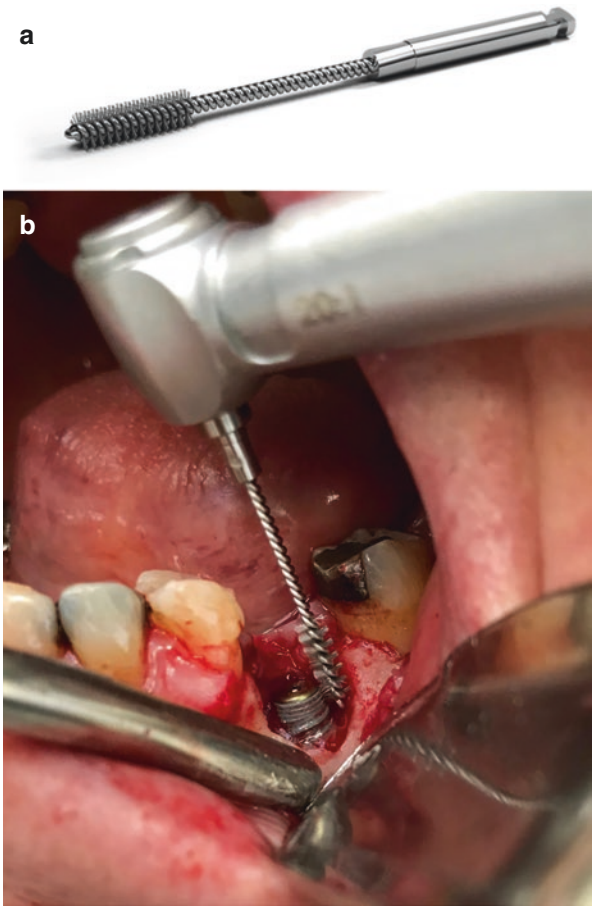


Fig. 15 (**a**) Image of Straumann® TiBrush™, (**b**) Intraoral photograph shows the use of TiBrush™ to debride titanium surface of the implant

7 Chemical

When it comes to chemical decontamination, it follows the mechanical debridement which removes the majority of the biofilm or biodebris. It is simply the application of the chemical agent on the implant surface. Then the remaining biofilm remnants can be eliminated with chemical ablation. Those chemical agents are aimed to destroy the remaining biofilm elements by chemical toxicity. On the other side, this chemical material can be hazardous to the surrounding vital tissues by the same chemical reactions. Regardless of the type of agent or application time decontamination of the chemical agent from the implant surface is mandatory. Especially during the application and removal of the chemical agent, the contact of the toxic chemical to the surrounding healthy tissues maximum effort should be practiced, minimizing this side-effect. Due to the higher viscosity feature, the gel form of the chemical materials might be advantageous over liquid forms during application to reduce tissue contamination, which can lead to necrosis or delayed wound healing.

Eventually, copious sterile saline irrigation with a high-volume suction would diminish the chemical contamination risk of surrounding tissues.

In general terms, the application of the chemical agent can be obtained with a cotton pellet or a micro-brush soaked with a chemical agent for 30–60 s and rinsing the surface with sterile saline solution. With this purpose, 10% hydrogen peroxide swabbing for 1 min [145], hydrogen peroxide-titanium dioxide suspension [146], citric acid 30–60 s [147, 148], 35% orthophosphoric acid gel for 1 min [149], 24% EDTA [148], and sodium hypochlorite have shown to be effective for chemical decontamination [146, 148, 150]. All the abovementioned chemical agents have been shown to provide successful decontamination of implant surfaces. So far, there is no homogenous data to compare those study results, which are mostly experimental, to point out as an ideal material for clinical practice. Nevertheless, following the gross debridement with mechanical approaches use of chemical decontamination seems more advantageous to eradicate any possible biofilm remnants. Further comparable clinical studies are needed.

On the other hand, with a parallel thinking way, topical use of antimicrobial agents has also been in focus for the treatment of peri-implant infections. The most commonly used agents are chlorhexidine, tetracycline, and doxycycline. Contrast to abovementioned chemical agents, which harm the microfilm elements regardless of their type, the efficacy of antimicrobials is limited to their spectrum, sensitivity, and their longevity on the implant surface. Once the vast diversity of the biofilm community in peri-implant infections is regarded, use of the topical antimicrobials for decontamination can have a minimal benefit, and significant clinical contributions to this treatment should not be expected.

7.1 Irradiation

7.1.1 Laser

As the laser beam carries high energy, which targets specific molecule as chromophore, it creates thermal destruction on the aimed structure. The increased temperature raise on the target can kill the microbiome with its photothermal effect [151], especially with the presence of the chromophore. This bactericidal effect can be achieved with lower energy settings [152]. This temperature rise can also melt the titanium on the focused spot and can alter the surface structure. Application time per unit time of the laser energy is directly related to the temperature rise on the target. A continuous beam flow loads more energy on the target and causes peaked temperature. On contrary, pulsed beam shots create less thermal increase comparing to continuous wave, however, creates micro beats on the target area (Fig. 16). With this understanding, short pulses can easily create cracks at crystal materials, like zirconia.

Decontamination of the peri-implantitis-related microbiome with lasers has been a discussion point between different study groups. The consensus about the use of lasers for peri-implantitis treatment is as an adjunctive tool, which can contribute to reduce the bleeding on probing score [153]. Since the physical (photothermal) and

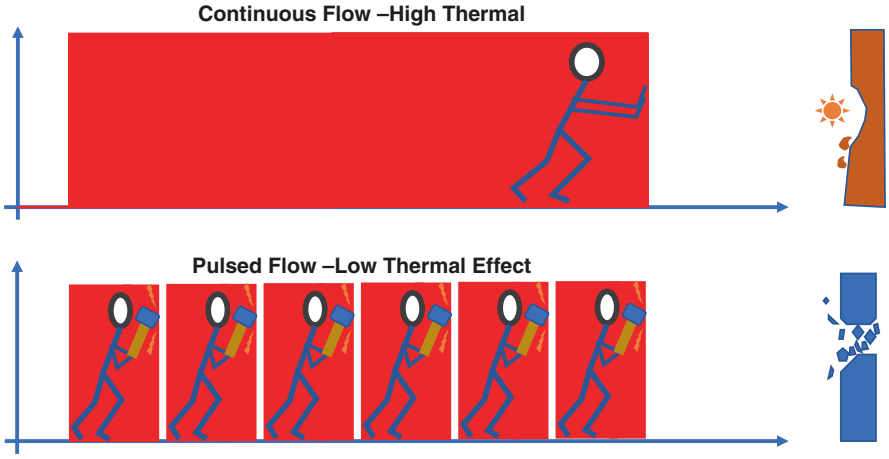


Fig. 16 Laser beam effect on the biofilm and implant surface, continuous flow (wave) creates more heat damage on the implant surface, while pulsed waves produce less heat damage

chemical (photodynamic) destructive effects of laser have been proved to provide strong antimicrobial efficacy, it looks a promising adjunctive tool for implant surface decontamination besides other methods [153, 154]. Erbium:yttrium-aluminum-garnet (Er:YAG) [155], erbium, chromium: Yttrium Scandium Gallium Garnet (Er,Cr:YSGG), CO_2, and diode lasers have been shown to have minimal effect on titanium surface, while killing the microorganisms on the implant surface [151, 153, 156].

For the zirconia implants, its crystalloid structure complicates the use of lasers due to any possible cracking effect on the surface. Even Er:YAG laser, with specific settings, is shown to have no surface alteration [157], the general acceptance is for the use of diode laser on zirconium implants for decontamination without surface changes [158, 159].

The clinical application of laser can be in three ways. Er:YAG or Er,Cr:YSGG lasers enable the clinician to remove granulation tissue around the implant, debridement, and decontamination of the implant surface, and removal of the infected bone surface by using different modes.

For granulation tissue removal, Er:YAG laser can be used with long-pulse mode (600 μs) at non-contact mode. This setting allows the ablation of soft tissue while minimizing thermal damage on the underlying bone. Then medium-short-pulse mode (100 μs) with an air-water spray can be used to remove the biofilm from the implant surface without any thermal damage. As the laser beam output angle is straight, lower aspects of implant surface or the undercut areas of grooves cannot be appropriately irradiated. Therefore, recently side-firing sapphire tips eliminate this physical access problem by delivering the beam with a right angle (Fig. 17).

Especially side-firing sapphire tips enable the clinician to debride the undercut areas of the implant threads (Fig. 18).

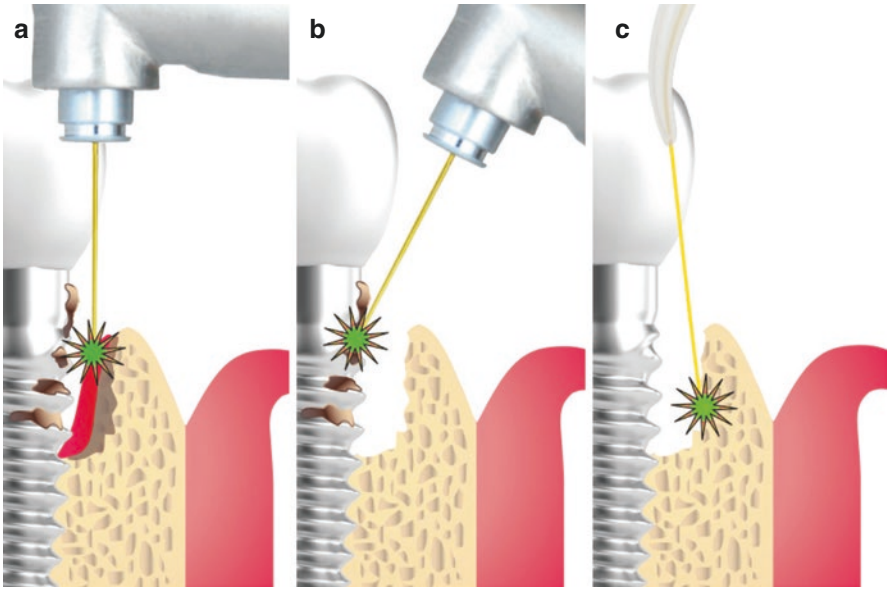


Fig. 17 Graphical illustrations show the use of Er:YAG and Nd:YAG lasers in different modes for peri-implantitis treatment. (**a**) Removal of the soft-granulation tissue with Er:YAG in LP mode and ablation of the infected bone with Er:YAG in QSP mode. (**b**) Removal of the bacterial biofilm on the implant surfaces with Er:YAG in MSP mode. (**c**) Bacterial reduction and biostimulation of the bone tissue with Nd:YAG in VLP mode (TwinLight®, Fotona, Ljubljana, Slovenia)

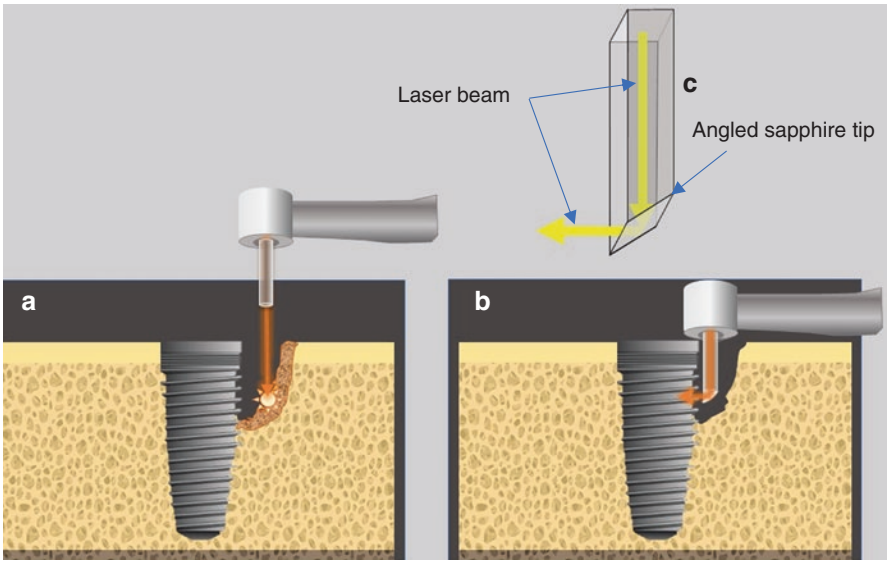


Fig. 18 Diagrammatic illustration demonstrates the use of Er:CrYSGG laser for peri-implantitis treatment. (**a**) Straight firing sapphire tip is used for removal of granulation and infected bone tissues. (**b**) Use of side-firing tip for the implant surface decontamination even at undercut areas. (**c**) Side-Firing Tip allows distribution of the laser beam to the implant surface with a right angle (Waterlase®, Biolase®, Irvine, California, United States)

Finally, debridement of infected bone tissue can be achieved with quantum-square-pulse or very-short-pulse modes under air-water spray at non-contact mode.

However, all the decontamination methods mentioned above do change the original implant surface texture and its reosseointegration potential [160]. To the current, there is no conclusive data available to suggest the best value for the implant surface decontamination. On the other hand, among the mechanical decontamination techniques using biocompatible powder with an air pressure system looks like it leaves debris which can contribute to reosseointegration. Further homogenous, long-term clinical studies are required.

7.2 Implantoplasty

This procedure is a radical debridement of the implant part. This technique can be preferred for the peri-implant infections that are not responding to the conventional non-surgical and surgical techniques, where the implant stability is still persistent. Especially, when the faster progression of peri-implant disease on the rough surface compared to machined-surfaces is regarded, removal of the superficial aspect of titanium surface can be expected to have a higher response to the treatment [161, 162]. Similarly, for those cases where the non-surgical treatment access is not possible to the affected implant surface, like periapical peri-implantitis, removal of the apical part of the implant can be considered.

On the other hand, the implantoplasty procedure also has some mechanical and biological risk potentials during and after surgery. During the procedure damaging the abutment or abutment connection, or implant body perforation is some of the intraoperative risks. During the grinding procedure due to high frictional forces, thermal damage risk on the surrounding bone and soft tissues is also available. Some of these intraoperative complication risks can be avoided by cautious grinding, copious irrigation, and use of HVS.

Following the disruption of mechanical integrity of the implant when the implant is loaded fracture of the fixation screw or implant body, screw loosening, and deformation of the implant collar area are possible outcomes. Moreover, scattering of titanium particles into the surrounding tissues can lead to inflammation and metal tattoo at the soft tissue. Those post-loading consequences are generally inevitable [163]. With this regard, implant design gains a critical role for longevity after the implantoplasty procedure. The narrow-diameter implants have a higher risk of failure after implantoplasty due to weaker tolerance to strain under occlusal forces, while wide-diameter (>4 mm) implants can pertain their resistance to the masticatory forces. Considering the bite forces are heavier at posterior and lower at anterior areas, location of the implant correspondingly increases the chance of survival of implant.

With the implantoplasty procedure, rough surface of the implant is converted to a machined surface, which will be in contact with soft tissue after healing. Therefore, maximum smoothness is targeted to minimize biofilm attachment. The lowest surface roughness can be achieved with gradually decreasing bur grit sizes. So far the use of diamond burs of 106 lm, 40 lm, 15-lm grit size at 200,000 rpm speed and then

Arkansas stone torpedo-shaped aluminum oxide bur at 40,000 rpm speed consequently has been shown to provide the most optimal solution to minimize the treated implant surface roughness.

8 Regenerative Surgery: Surgical Techniques

Following a mucoperiosteal flap elevation at the implant site, the removal of granulation tissue from the implant and bone surfaces should be carried out. Then the debridement and decontamination of affected implant surface(s) and infected bone surface debridement with curettes or burs should be finalized before regenerative techniques.

Definition of the bone defect and the missing volume mandates the choice of technique for reconstruction. The surgeon's experience and knowledge on the technique choice have also an essential role in this preference, as well as material choice.

Advantages and disadvantages of bone graft, membrane, and guided-bone-regeneration (GBR) materials are discussed in detail in another chapter. As the same biologic principles are applied to the peri-implantitis-related bone defect reconstructions, basically the autogenous bone graft is highlighted as the gold standard. Especially for minor defects, the autologous bone can easily be harvested with minimal trauma. Use of a membrane cover over the autogenous bone graft particles would improve the success rate of reosseointegration [164]. The advantage of combining autologous material with allogenic, xenogenic, or alloplastic materials to improve the healing should be regarded (Fig. 19). With this purpose, platelet-rich-plasma of platelet-rich-fibrin options may offer favorable results during the healing process [165]. However, advanced scientific proof with well-designed randomized clinical trials is still needed. Though the controversial reports about one

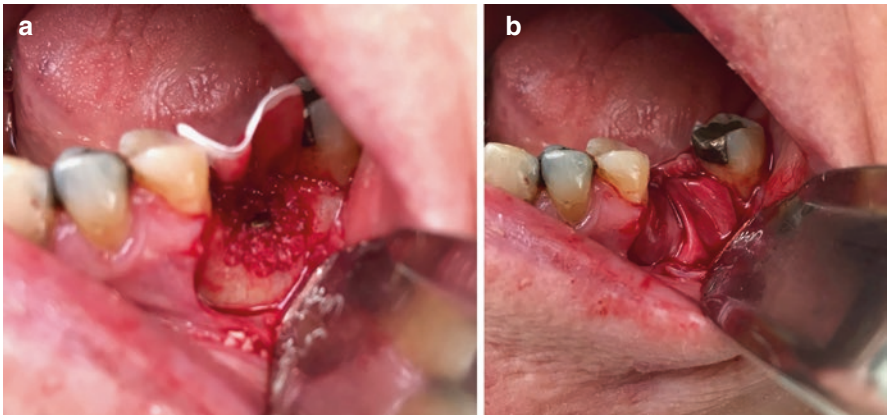


Fig. 19 Intraoral photograph demonstrates the use of xenogenic bone grafting for the reconstruction of peri-implantitis related bone defect. (**a**) Bone graft particles were packed around the peri-implant defect. (**b**) Site is being covered with resorbable membrane

morphogenetic protein (rhBMP-2) use for peri-implant defects, the consensus is that their combination with a scaffold material is recommended [166, 167].

Membrane use over the graft material or for GBR, load-bearing efficacy comparing to exposure risk under the mucosa and removal necessity with a second surgery should be regarded for non-resorbable membranes. However, resorbable materials have different features comparing to non-resorbable membranes. Nevertheless, they have a potential advantage, slow drug-releasing, which might improve bone healing, over non-resorbable ones.

Before these regenerative techniques, causative local or general factors should be eliminated. Removal of the implant from occlusion would improve the healing reaction.

9 Bone Reconstruction Techniques

The definition (vertical or horizontal) and amount of bone defect determines the choice of reconstruction technique.

9.1 Vertical Defects Less Than 3 mm

Regardless of the material selection, the graft material should be condensed into the defect area and over-filled owing to the fact that it will undergo some resorption after placement. For the vertical defects around the implant body, which is not more than half exceed, three options can be used for reconstruction:

1. Removal of prosthetic part or healing abutment and placing a 0 mm height-healing cap would allow submerging the implant under the mucoperiosteal flap and its primary closure after reapproximation. As the first option, filling the defect with bone graft material and covering with a resorbable membrane or placing a GBR material can be preferred (Fig. 19). In that case, the site is left for healing 3–4 months and followed up for the second-stage procedure to uncover the implant.
2. Only the bone defects neighboring to edentulous sites can be filled with a bone-wedge osteotomized and moved into the defect area from the adjacent edentulous alveolar bone. However, the mobilized bone segment should be stabilized by supporting with some bone graft material at the donor site, so that resorption of this mobilized wedge is minimized (Fig. 20). Healing abutment or prosthetic abutment of the implant is replaced with 0 mm height-healing cap. Then the mucoperiosteal flap is primarily closed by submerging the implant and the grafted site. Between 2 and 4 months of the healing time is given before exposure of the implant.
3. After an implantoplasty procedure, osteoplasty procedure can be an alternative to especially after a failed bone grafting attempt. The small vertical defect between the bone and resurfaced implant site also requires pocket elimination, likewise a crown-lengthening procedure. Reduction osteoplasty at the sharp

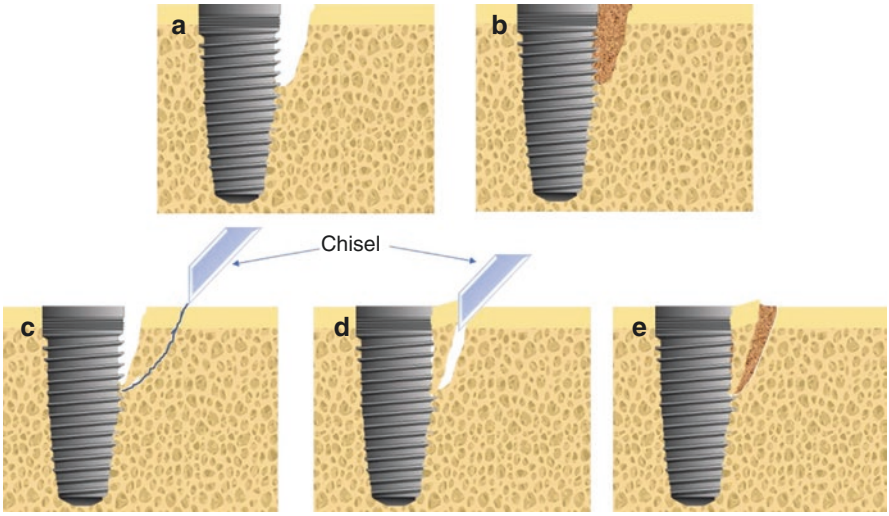


Fig. 20 Illustration compares simple bone grafting versus bone-wedge osteotomy techniques for the reconstruction of periimplant bone defects. (**a**) Bone defect around the implant. (**b**) Filled bone defect with bone graft. (**c**) Use of chisel to elevate a wedge shape bone segment around the defect area. (**d**) Raised bone segment is approximated to the implant surface. (**e**) Bone graft is filled into the donor area

bone margin is used to widen the angle between vertical bone and implant surface. Finally, the mucoperiosteal flap placed more apically to its new position. Mucosal healing abutment can be placed immediately.

9.2 Vertical Defects More and Equal to 3 mm

Replacement of upper structure with 0 mm height-healing cap is necessary for predictable healing. After removing the previous upper structure, inner aspect of implant body should be flushed with saline thoroughly to remove any possible biodebris, and last irrigation is done with 0.12% chlorhexidine solution. Then the healing cap is placed. After site preparation with the removal of granulation tissue, implant surface debridement and decontamination, infected bone surface scraping, those defects are reconstructed with bone graft material with membrane placement or GBR technique. Then the implant and reconstructed site are laid under the flap for healing approximately 2–4 months. Bone defects larger than 3 mm which are equal to or more than half of the intraosseous implant height might necessitate removal of the implant.

9.3 Horizontal Defects Smaller Than Half of Implant Diameter

Several factors in the treatment planning of horizontal bone defects around an implant play role. Type of supported upper structure, esthetic visibility of implant,

implant length, vertical depth, and amount of horizontal loss of bone are the significant factors that lead the treatment plan.

For the defects, which are less than half of the implant perimeter, the most predictable method is soft tissue pocket reduction. This procedure is similar to crown lengthening as performed in natural teeth and causes exposure of implant body into the mouth. As the rough surface would aid biofilm deposition, the treated implant surface must be smoothened with implantoplasty. At posterior areas, if the patient has no esthetic concern, this smoothened implant surface can be left as it is with maximum oral hygiene instructions and follow-ups. At the anterior esthetic zone, a cement-retained crown with extended margin up to the new marginal gingival line can be considered to cover the implant body. Depth of the horizontal bone defect is also another critical aspect of the treatment decision. If the vertical depth of the defect is more than the implant height, the clinician can reconstruct the site either with graft and membrane or GBR. However, if the crown/root ratio is more for the crown part, removal of implant and bone reconstruction of the explantation site is more predictable.

Ideally, the second option is the bone regeneration technique to replace the horizontal bone loss. The success predictability is higher in smaller defects. The initial step is the replacement of the current upper structure with a healing cap 0 mm height. After removing the upper structure, internal area of the implant is irrigated with saline and then 0.12% chlorhexidine solution, then the closure cap is placed. For a proper bone formation debridement and decontamination of the implant surface, curettage of the bony wall not only to debride the inflammatory remnants but also to improve the blood perfusion is necessary. As the perfusion of the graft material is limited to apical and lateral walls, this bone regeneration attempt has a lower success rate comparing to vertical bone defects. Preferably autogenous bone or combination of other types of substitutes with BMP-2, or autologous blood-derived co-products (PRP or PRF) could be used. To avoid connective tissue cell migration, the grafted area is covered with a barrier membrane, and the site is closed primarily by submerging the implant under the flap. Depending on the volume of defect, 12–16 weeks healing time should be given for bone healing and reosseointegration on the implant surface.

9.4 Horizontal Defects Larger Than Half of Implant Diameter

There is a predictable physiologic MBL all-around the implant body. When the horizontal bone loss around the implant is beyond the documented expectation, initially etiological factor search must be carried out, and salvage of implant option should be reviewed. Besides the management of local and systemic factor, bone regeneration techniques are suggested. However, biomechanically the implant features are not satisfactory, as described by Resnic, removal of the implant when the horizontal bone defect is greater than half of the implant body is carried out [168]. Explantation site then must be grafted for next implant placement.

10 Implant Removal: Explantation

Removal of an implant is mandatory, if the implant body has proven mobility, previous attempts to save the implant fail. Especially, recurrent pain or suppuration, which is not responsive to any treatment, may indicate the removal. Also, the patient's adaptation to implant treatment due to either psychologic or esthetic causes is another factor to consider explantation. Unproperly placed implants, which cannot be restored, should be removed. Finally, when the nerve canal violation is noticed immediately after placement of the implant, similarly removal and replacement with a shorter implant can be considered. Severe infections originated from peri-implantitis, malignancies develop around an implant, or implants on a jaw fracture line also should be removed. Finally, fractured implants or non-retrievable abutment-screw fracture are the other indications to remove an implant.

The removal of already mobile implants is pretty simple. Generally, following the removal of the upper structure, use of high torque wrench with fixture placement/removal tool in counterclockwise direction is sufficient [169]. Even implants with slight mobility can easily be removed with this technique. However, in patients with osteoporosis of severe atrophy, iatrogenic fracture risk should be considered, when there is a resistance to the reverse torque wrench application. Then following reflection of a mucoperiosteal flap, counterclockwise rotation of the implant can provide a safer approach with improved visibility during removal. For this purpose, dental elevators or forceps can also be utilized to mobilize and remove the implant. Debridement of the granulation tissue from the bone, irrigation with saline, and reconstruction with a bone graft or GBR are the following steps before primary flap closure.

However, if there is no mobility on the implant, removal of implant is performed with surrounding bone. Preoperatively relation with the surrounding anatomical structures must be evaluated to avoid damages on these vital structures, like adjacent teeth, inferior alveolar nerve, or maxillary sinus. Trephine bur 0.4–0.6 mm larger than implant diameter can provide a reasonable coverage and less damage risk to the surrounding structures. If there is, the crown is removed for the access of trephine bur. After the rise of a mucoperiosteal flap, trephine bur placed on the implant with a parallel long axis to implant and drills along the implant body until 1–2 mm above the apex level to avoid damage to underlying nerve or sinus, if available. Copious saline irrigation is used. For the implants with a broader collar diameter than the implant body, this width differentiation should be eliminated with an implantoplasty at the collar to minimize bone damage during drilling with the trephine bur. Then implant can be removed with rotation or buccolingual movements with elevator and/or dental forceps. Similarly, a 701-fissure bur can be used to remove the implant by creating a box osteotomy around the implant. In either way, after implant removal curettage of granulation tissue and saline irrigation steps are followed for bone reconstruction with grafting or GBR.

11 Complications of Peri-implantitis

The most predictable outcome of untreated peri-implant infection is the loss of alveolar bone, leaving a significant defect behind, especially when implant removal is needed. Immunocompromised (like in diabetic or HIV) patient groups the spread of infection to the adjacent tissues and teeth could be expected. Direct spread to the bone marrow can lead osteomyelitis of the jaw bone [170].

Advancement of peri-implant infection is one of the chief reasons for bone loss, which mainly may cause pathological mandibular fracture [171]. With the extension of peri-implant infection apically at posterior maxillary area, an infection can spread into the sinus. Besides maxillary sinusitis possibility, an oroantral fistula formation or dislodgement of the implant into the sinus cavity with the occlusal forces can also be expected [172].

MRONJ has been another concern related to implant treatment. A recent study reveals that not only surgical trauma of implant placement but also the presence of an implant is a risk factor for the development of MRONJ [173].

12 Pathologic Lesions Around Dental Implant

As a rare but not a very uncommon condition, development of inflammatory or malignant lesions is possible. More commonly, development of pyogenic granuloma, peripheral giant cell granulomas, or capillary hemangioma around the dental implants has been shown after placement [174–178]. Due to the reactive nature of those lesions, oral hygiene maintenance gains additional importance to minimize the development of such lesions. For the removal of those lesions, Er:YAG laser can provide safe resection with good hemostasis feature besides minimizing the damage to the implant surface [177].

So far, the development of oral squamous cell carcinoma around a dental implant has been shown in several cases [179, 180]. The lesions non-responding the treatment or with an unusual appearance on the soft tissue mandate biopsy.

13 Corrosion and Implantoplasty Co-products

Under recycling occlusal wears and dissolving effect of body fluids, titanium, as an inert material, can undergo corrosion. The restoration materials of titanium-based implants have a critical role in synergistic interaction between wear and corrosion. Combination of different materials to restore an implant can lead to different wear-related corrosion potentials. For example, zirconia abutment over zirconia implant presents least wear-related volume loss of material, while titanium over titanium couple has the most advanced corrosion feature [181]. The released corrosion products, which can be in microparticle and nanoparticle size or at ion level, may induce inflammation at peri-implant tissues that can lead to pathologic bone resorption [182].

Moreover, during the implantoplasty procedure, the removed titanium particles can easily be scattered into the surrounding tissues and are related to ongoing inflammation after the procedure [183]. Further studies are needed to verify titanium corrosion products related to tissue reactions.

14 Summary

Current concepts for the management of peri-implant diseases are focused on the salvage of the problem. However, preventive measures listed below have a more critical role in terms of prophylactic measure for peri-implantitis development.

1. Preoperative assessment of the host defense and present infections to hold under control and eliminate, respectively, before the implant placement is mandatory.
2. Proper planning, the precision of implant application, and its prosthetic restoration are also inevitable steps to prevent implant-related infections.
3. Drawing the patients' attention to infection and failure risk, improving the oral hygiene level to maximum level, and holding them under strict recall schedule can reduce such infection risks.

When peri-implant infections (either peri-implantitis or peri-implant mucositis) are encountered besides the infection treatment, the contributing factors, such as the systemic condition of the patient, upper-structure-related issues, and bruxism should also be considered and managed before attempting to treat peri-implantitis and related bone loss.

Elimination of the implant from occlusion and correction of related systemic health problem should also be considered to aid the healing. Removal of granulation tissue, curettage of the bony surface is the first surgical step. Then mechanical debridement of implant surface and decontamination of the implant surface must be performed consequently to improve antimicrobial elimination effect. Followed with primary closure with or without bone grafting is the primary goal of peri-implant infection treatment.

Strict follow-up agenda and increasing the awareness of the patient to improve oral hygiene practice are as important as previous stages.

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Preventing and Treating Dental Implant Complications from Drugs Known to Cause Osteonecrosis of the Jaws

Robert E. Marx

Drugs known to cause Osteonecrosis of the Jaws (ONJ) can and do affect dental implant practices. However, most all are preventable or can be treated if ONJ results. It requires a knowledge of the drugs pharmacodynamics, a detailed review of radiographs, careful patient selection, and the judicious use of drug holidays in most cases.

Today, the practicing clinician is called upon to see groups at risk for Drug Induced Osteonecrosis of the Jaws (DIONJ-ICD-10M87.10): The patients are mostly being treated for osteoporosis where as other patients are being treated for metastatic cancer deposits in bone. Each group and each individual must be planned and treated individually.

1 Section I: The Patient with Osteoporosis

1.1 Drugs Known to Cause DIONJ in the Treatment of Osteoporosis

There are numerous drugs currently used to treat osteoporosis most all of which are also used to treat osteopenia even though none are FDA approved to do so. Therefore, prudent clinicians should include questions about osteopenia as well as osteoporosis in their medical history forms. Osteoporosis is more common in certain individuals and in certain groups. The prudent clinician should be alert for postmenopausal women which is the most common group to develop osteoporosis due to their loss of estrogen which is required for osteoblast differentiation and function. Within this broad group are two specific groups, white Caucasian women and Asian women

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Table 1 Current osteoporosis drugs

	Risk order for DIONJ			
Risk order	Drug	Dose/frequency/route	Type	Bone half-life
1.	Alendronate	70 mg/week: ORAL	Bisphosphonate	11.2 years
2.	Denosumab	60 mg/6 months: SC	RANK-L inhibitor	26 days
3.	Zolendronate	5 mg/year: IV	Bisphosphonate	11.2 years
4.	Residronate	35 mg/week: ORAL	Bisphosphonate	11.2 years
5.	Ibandronate	150 mg/month: ORAL	Bisphosphonate	11.2 years
6.	Romosozumab	105 mg/2 weeks: SC	Sclerostin inhibitor	12.8 days

who are at the greatest risk for osteoporosis even though women of any race or ethnicity may develop postmenopausal osteoporosis. Others include patients taking steroids or methotrexate. These are patients usually being treated for a rheumatologic condition. Additionally, some chemotherapy patients without bony metastasis are treated with aromatase inhibitors such as anastrazole, letrozole, and exemestane which cause osteoporosis and which may be undergoing osteoporosis therapy with a bisphosphonate or a RANK ligand inhibitor. The common drugs used for these two conditions include the oral bisphosphonate drugs alendronate, residronate, and ibandronate; the subcutaneous injection drugs denosumab which is a RANK L inhibitor and recently romosozumab which is a sclerostin inhibitor as well as the IV bisphosphonate infusion drug Zolendronate. See Table 1.

1.1.1 Oral Drugs Known to Cause DIONJ

These are all in the bisphosphonate class of drugs. That is, they theoretically improve osteoporosis by killing or impairing osteoclasts mostly as they resorb bone in their normal function of bone remodeling and rebuilding [1]. Therefore, they retain existing old bone and actually inhibit its replacement with new bone. This causes bone density to increase improving osteoporosis scores called T scores gained from a radiograph called the Dual Energy X-ray Absorptiometry scan or the DEXA scan. This retention of old bone which becomes brittle with long-term use has caused some long bones to become too brittle resulting in femur fractures [2] in addition to the DIONJ the dental profession faces (Figs. 1 and 2).

The risk for DIONJ is related only to the drug itself and is in turn related to the drugs potency, its dose, its frequency of use, its half-life in bone, how long it has been taken, and when the patient took the last dose.

Therefore, the prudent clinician should include the following specifics in their medical history forms:

1. What osteoporosis drug have you taken?
2. How frequently did you take it?
3. How long have you been using this drug?
4. When did you last take this drug?
5. What general medicines are you now taking?
6. For what medical conditions are you now being treated?

It should be noted that the half-life of all bisphosphonates in bone is 11.2 years [3]. It should also be noted that alendronate is the most potent and

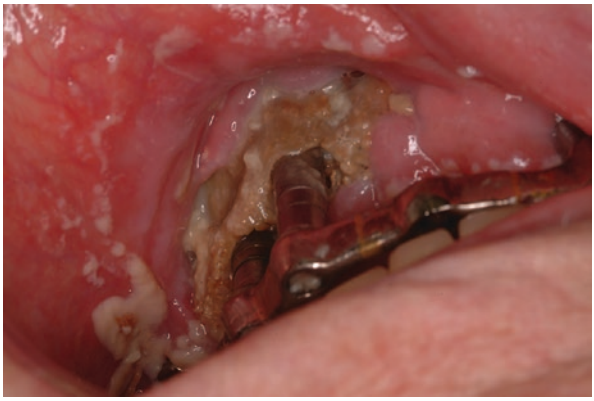

Fig. 1 Drug-induced osteonecrosis of the maxilla due to alendronate

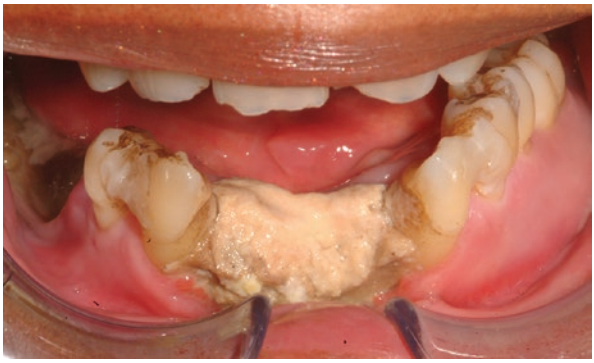

Fig. 2 Drug-induced osteonecrosis of the mandible due to alendronate

is prescribed at the highest dose (twice that of residronate and ibandronate) [4] See Table 1.

1.2 Drug and Potency

As noted in Table 1, alendronate is the most potent of all the oral bisphosphonates and is prescribed at twice the dose 70 mg/week as compared to 35 mg/week. This is why 96% of DIONJ in osteoporosis patients seen by this author and treated with an oral bisphosphonate resulted from alendronate. This should represent a particular note of caution to the clinician when identified in the medical history.

1.3 Frequency

Most oral bisphosphonates are taken once each week. However, due to the esophagitis commonly reported by women taking oral bisphosphonates leading to noncompliance, ibandronate was desgined to be taken at 150 mg each month. This averages to 35 mg/week equivalent to residronate but only half the dose of alendronate. Since the half-life of bisphosphonates is 11.2 years, the weekly versus monthly frequency makes no difference.

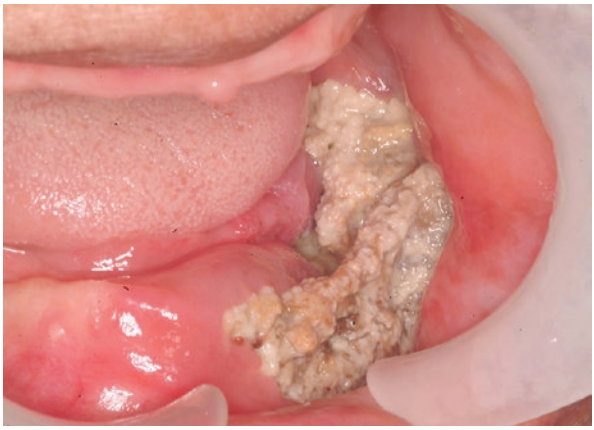

Fig. 3 A more extensive drug induced osteonecrosis if seen in this patient after 15 years of alendronate

1.4 Length of Use

This is probably the most important question to be answered. Essentially, due to its very long half-life, bone toxicity from bisphosphonate is caused by an accumulation of the drug in bone. When a patient ingests an oral bisphosphonate only 0.68% is absorbed in the gut [4, 5]. Before it becomes irreversibly bound to the hydroxyapatite in bone, 30% is eliminated by kidney function. Therefore, it takes from 2 to 3 years to build up a sufficient amount in bone to pose a risk for ONJ in most people. Note, the risk factor may begin at 2 years but due to genetic vulnerability and/or genetic resistance it may occur sooner or later in some individuals. Therefore, the prudent clinician should recognize a concern in any patient taking a bisphosphonate for 2 years or more and realize a proportionately greater risk each year beyond two (Fig. 3).

1.5 Last Dose Taken

The reason for the long half-life in bone of bisphosphonate is that when an osteoclast resorbs bone ladened with molecules of bisphosphonates it rapidly swells, bursts, and dies within 12–24 h (Fig. 4a, b). As it bursts it liberates the ingested bisphosphonate molecules most of which are immediately taken back up by the open bone surface in the Howship's lacunae to affect the next osteoclast that comes along. Only a small percent is taken up in the circulation and eliminated by the kidneys. This understanding is critical to the effective application of drug holidays for dental implant surgery and all other surgeries within the alveolar bone in such patients i.e., tooth removals, periodontal osseous surgery, crown lengthening, root resections, etc. This is because the minimal absorption of the oral bisphosphonate in the gut creates only a trickle effect into the bone taking 2 years or more to load the bone to significantly toxic levels. During that time, the bone marrow osteoclast precursors are able to replenish the lost osteoclasts so that during a drug holiday the bone marrow begins replacing osteoclasts to a functional number by 9 months.

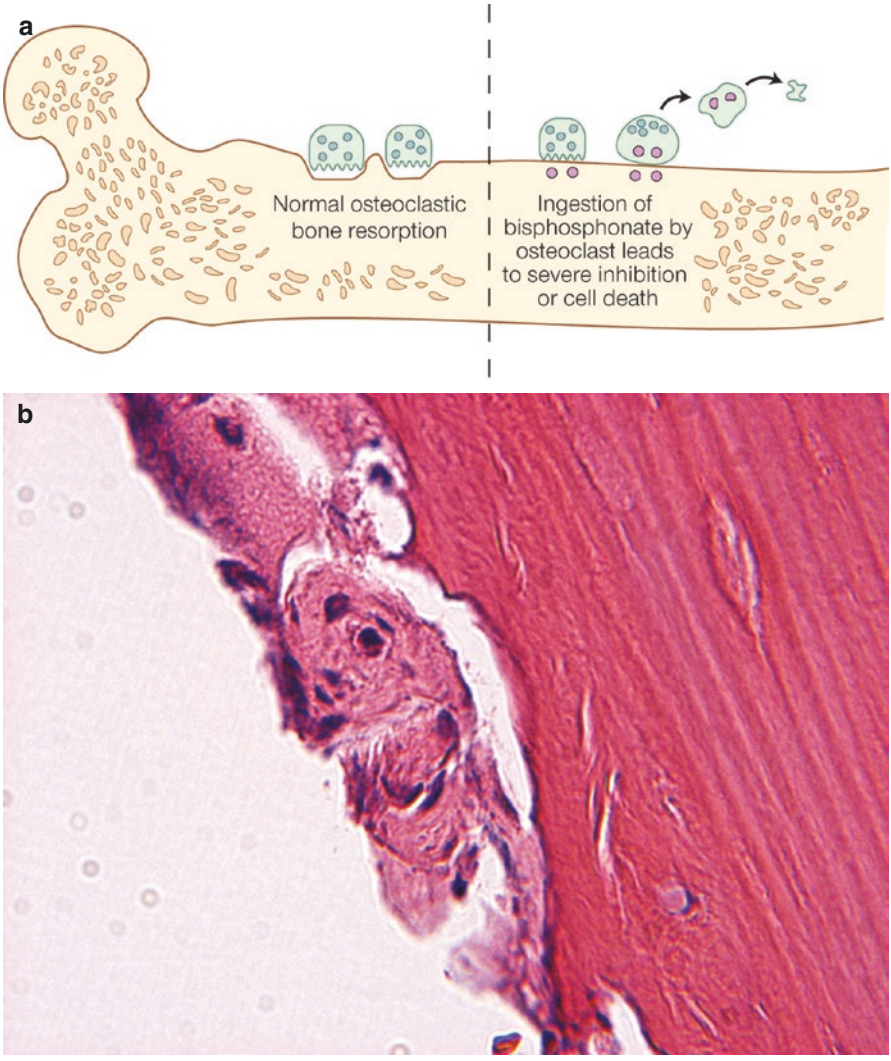

Fig. 4 (**a**) Osteoclasts resorbing bone ingesting bisphosphonate molecules, swelling, then bursting. (**b**) Photomicrograph of swollen ding osteoclast after resorbing bone containing alendronate (original magnification 40×: hematoxylin-eosin stain)

1.5.1 Safety of Dental Implantology in Patient Taking Oral Bisphosphonates Using an Appropriate Drug Holiday

Several studies using the bone biochemical marker for osteoclast activity have proven the effectiveness of the morning fasting serum C-terminal Telopeptide Test (CTX) [6–9]. Research testing and clinical experience has also shown that a 9 month drug holiday from any of the oral bisphosphonates followed by a 3 month drug

holiday after the procedures imparts a 99% safety for alveolar bone healing and osseointegration of implants in these patients.

Such drug holidays should not be initiated by the treating dental provider without the consent of the prescribing physician. In this author's experience, nearly all prescribing physicians are readily willing to initiate the drug holiday. To assure them of the osteoporosis safety during a drug holiday I specifically refer them to the sentinel, randomized prospective, double blinded, 10-year study by Black et al. [10], which identified that a drug holiday of 5 years did not increase fracture risk due to osteoporosis. The drug holiday for the safety of dental implant procedures in the osteoporotic patient who took an oral bisphosphonate is only 1 year. I also include the following list of osteoporosis drugs related to the level of risk for ONJ for the physician to consider as a temporary or long-term replacement of the patients current therapy for the prescribing physicians information and guidance.

High Risk:	Oral alendronate 70 mg once weekly
	Subcutaneous denosumab 60 mg once every 6 months.
Moderate Risk:	IV Zoledronate 5 mg once each year
	IV ibandronate 150 mg once each month
Minimal Risk:	Ora residronate 35 mg once weekly oral Ibandronate 150 mg once each month
No Risk:	Oral raloxifene 60 mg daily
	Oral vitamin D3 and calcium daily
	Oral strontium renelate or strontium citrate
	Subcutaneous teriparatide which is recombinant human parathyroid hormone 1–34 (rhPTH1–34) 20 μg daily for 24 months.
	Subcutaneous abaloparatide—recombinant human parathyroid hormone 1–34 (rhPTH-1–34) 80 μg daily for 24 months.

1.6 The Value and Limitations of the CTX Test

The morning fasting serum CTX test has been an unfortunate cause of confusion and denial by some. It is not included in any of the AAOMS position papers and even those of other organizations [11–13]. This is a product of a misunderstanding of what the CTX actually tests and the individual patients to which it applies. That is, the CTX measures an eight amino acid sequence of collagen that is split off during bone remodeling/renewal. It is therefore an index of osteoclast activity. Because of its diurnal variance, the CTX is only accurate if the serum is drawn in a fasting patient and in the morning. Additionally, the CTX is not valid in the cancer patient with DIONJ because the cancer gives off collagen split products which cross react with the CTX test to register a reading consistently too high and therefore misleading. The CTX is also not valid in any patient taking steroids or recently took steroids which suppresses the amount of collagen in bone. Therefore, the CTX reading is too low and will be misleading as well. Similarly, patients taking or who recently took methotrexate which suppresses osteoclast development will also register a CTX reading that is consistently too low. Both of these drugs will provide a too low

misleading CTX value. The rheumatologic patient is often taking either one or both of these medications.

Therefore, the CTX test is only valid in the uncompromised osteoporotic patient in which the blood draw has been in the morning and in a fasting individual. It is this misunderstanding that has led to the invalid criticism of the CTX test.

1.6.1 Representative Case Examples

Case Example #1:

A 64-year-old postmenopausal woman began alendronate 70 mg/week 14 months ago. Her medical history poses no comorbidities or the taking of drugs that would compromise dental implant surgery. She is a candidate for two dental implants to restore missing teeth.

Recommended Course of Action:

1. Request a drug holiday from alendronate for the 3 months after the implant surgery to secure initial healing
2. Proceed with dental implant placement without a preoperative drug holiday due to the history of only 14 months on alendronate which his below the risk threshold.
3. Allow 6 months of osteointegration before functional loading of the implants.

Case Example #2:

A 69-year-old postmenopausal woman began taking alendronate 5 years ago. Is now a candidate for an "all on four" dental implant treatment plan. Her medical history poses no comorbidities that would compromise dental implant surgery.

Recommend Course of Action:

1. Request a 9 month drug holiday (a morning fasting serum CTX test is optional).
2. Place four dental implants observing the "all on four" dental implant protocol after the 9 month drug holiday.
3. Continue the drug holiday for 3 months after the procedure.
4. Allow 6 months for complete osteointegration before functionally loading implants.

Case Example #3:

A 74-year-old osteoporotic woman with a history of controlled rheumatoid arthritis who now takes prednisone 10 mg/day and was discontinued from methotrexate 1 year ago. Her maximum prednisone dose was 40 mg per day. She took ibandronate for 2 years, then residronate for 2 years, and has now been on alendronate for 4 years. She is referred to you to accomplish a sinus augmentation and ridge graft for dental implants. Her CTX is 64 pg/mL.

Recommended Course of Action:

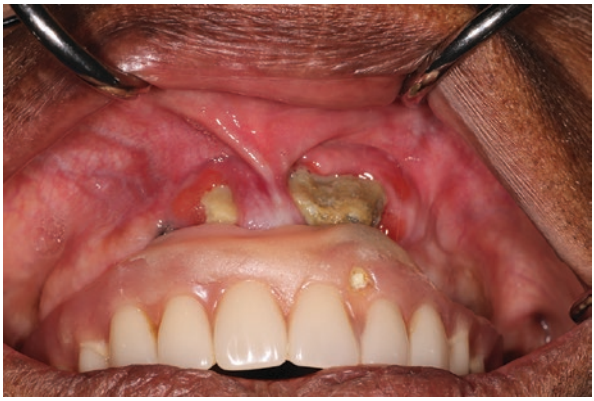

Fig. 5 Painful exposed bone in drug induced osteonecrosis due to secondary infection

1. Request a 3 month discontinuation of the prednisone.
2. Accept that fact that the CTX is not valid in this case due to the history of prednisone and methotrexate.
3. Request a 9 month drug holiday from the treating physician and provide him/her with the list of alternative drugs with the risk levels for DIONJ.
4. Proceed with the planned surgery and consider upregulation of bone regeneration using PRP and/or bone marrow aspirate and/or rhBMP-2/ACS.
5. Allow 6 months for full bone maturity before placing implants.

2 Resolving DIONJ to Prepare a Patient for Dental Implants in Osteoporotic Patient

2.1 Infection Control in DIONJ

Many patients will present with exposed bone that prevents implant placement at first. The exposed bone may or may not be painful. The exposed bone is necrotic and not painful by itself. It becomes painful when it is colonized by the oral bacterial flora or when actually secondarily infected (Fig. 5). Such infection is often the driving force that extends the DIONJ to involve more alveolar bone or progresses toward the inferior border or into the maxillary sinus in the posterior maxilla. Therefore, it is useful to treat patients that experience pain with antibiotics and 0.12% chlorhexidine oral rinses. Since the most common bacterial species found in DIONJ is actinomyces, penicillin is the drug of choice followed closely by doxycycline. Amoxicillin at 500 mg three times daily or doxycycline 100 mg daily along with 0.12% chlorhexidine oral rinses three times daily will significantly reduce pain during the 9 month drug holiday period required in most cases. The author has also found adding a short course of metronidazole 500 mg three times daily limited to 10 days to either of these two antibiotics to be useful in cases refractory to a single antibiotic alone.

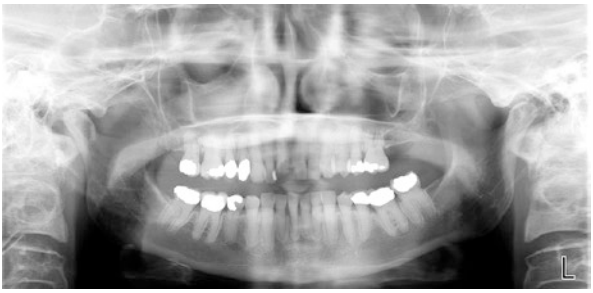

Fig. 6 Stage O DIONJ: Sclerosis of the lamina dura and widened periodontal membrane space without exposed bone

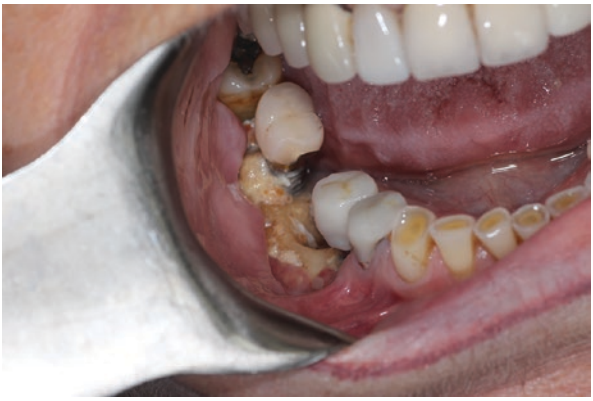

Fig. 7 Stage I DIONJ: One quadrant of exposed bone

2.2 Staging DIONJ in the Osteoporosis Patient

The staging of DIONJ in the osteoporotic patient is identical to that for the patient with metastatic cancer. However, the following staging system is more straightforward and very different from those proposed by most dental and medical organizations in their position papers [12, 13]. This is because those paper use pain as a criteria in staging. Since pain is subjective and can be modified by analgesics and antibiotics such staging systems have not accurately related either the extent or the severity of DIONJ. Moreover, no other staging system such as the TNM staging system for oral cancer or the Ann Arbor staging system for lymphoma includes pain in their stratification. The following staging of DIONJ is more clinically useful to assess the actual extent, and severity of DIONJ as well as to guide treatment and establish a prognosis.

Stage O:	There is radiographic or clinical evidence of bisphosphonate, denosumab, or other drugs toxicity to bone without exposed bone. This may be seen as a sclerosis of the lamina dura and/or a widened periodontal membrane space or a diffuse intramedullary hyper mineralization on radiographs (Fig. 6). It may also present as deep bone pain or tooth mobility not explained by obvious caries, periodontal disease, or traumatic occlusion.
Stage I:	One quadrant in which there is exposed bone (Fig. 7)

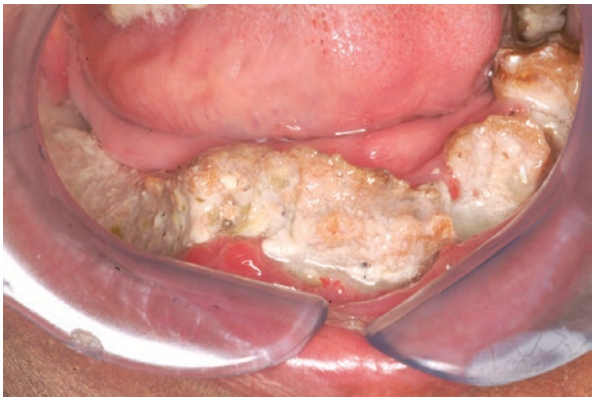

Fig. 8 Stage II DIONJ: Two quadrants of exposed bone

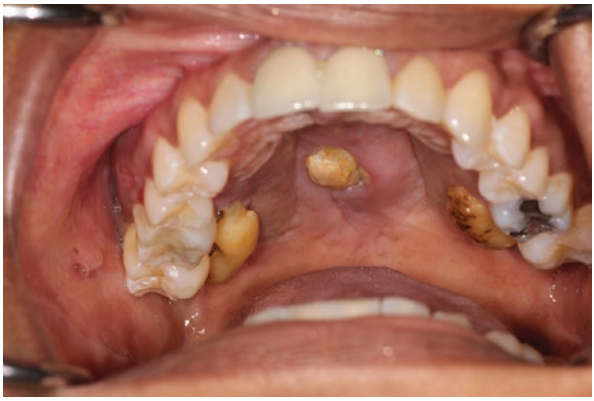

Fig. 9 Stage III DIONJ: Three quadrants of exposed bone (i.e., two quadrants in maxilla plus a palatal torus)

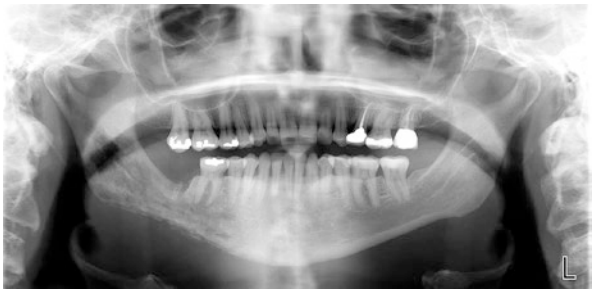

Fig. 10 Stage III DIONJ: Osteolysis to the inferior border of the mandible

Stage II:	Two quadrants in which there is exposed bone (Fig. 8)
Stage III:	1. Three or four quadrants in which there is exposed bone or (Fig. 9)
	2. Osteolysis to the inferior border of the mandible or (Fig. 10)
	3. Extension into the maxillary sinus or nasal cavity or (Fig. 11)
	4. The presence of a pathologic fracture (Fig. 12)

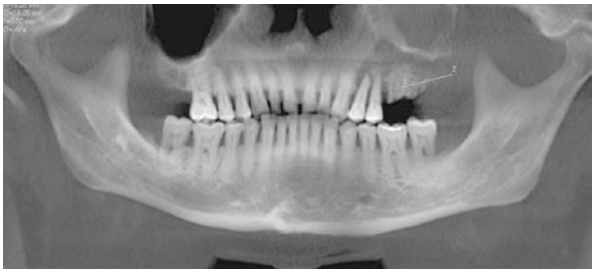

Fig. 11 Stage III DIONJ: Extension into maxillary sinus

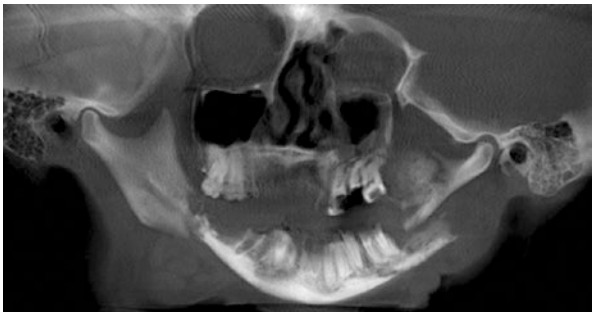

Fig. 12 Stage III DIONJ: Pathologic fracture of the mandible

2.3 Principles of Resolving DIONJ in the Osteoporotic Patient

The key to resolving DIONJ in the osteoporotic patient is the use of a drug holiday. For patients in which the DIONJ was caused by a bisphosphonate one should request a full 9 month drug holiday unless a morning fasting serum CTX test is over 150 pg/mL. During the drug holiday, control infection with amoxicillin 500 mg four times daily or doxycycline 100 mg once daily together with 0.12% chlorhexidine oral rinses three time daily. Note, one should refrain from using ampicillin with clavulanate as long-term use will often cause nausea and/or diarrhea due to the clavulanate in this preparation. Also when prescribing doxycycline, caution the patient not to use dairy products 1 h before or within 1 h after taking the medication because the dairy product will prevent its absorption in the gut.

During the drug holiday osteoclasts return in adequate numbers to remodel and renew bone for bone healing. Therefore, although the alveolar bone remains loaded with molecules of the original bisphosphonate the amount is slightly less and there are sufficient osteoclasts produced by the bone marrow to scavenge damaged bone or bone separated from its blood supply and in doing so regenerates bone for healing a defect and for osseointegration.

After completion of the drug holiday the exposed bone is seen to spontaneously sequester and exfoliate resolving the DIONJ in up to 50% of cases. In cases where this does not occur, an involucrum forms indicating an incomplete sequestration. In such cases, an office surgery removing the necrotic bone can be done (Fig. 13). In most cases, the necrotic bone is easily separated from the viable native bone. After 2–3 months, the soft tissue is sufficiently healed and mature to proceed with either

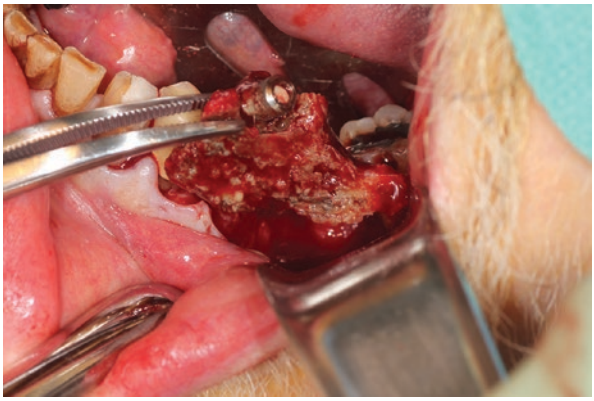

Fig. 13 Sequestrectomy of necrotic bone after a 9 month drug holiday from the oral bisphosphonates

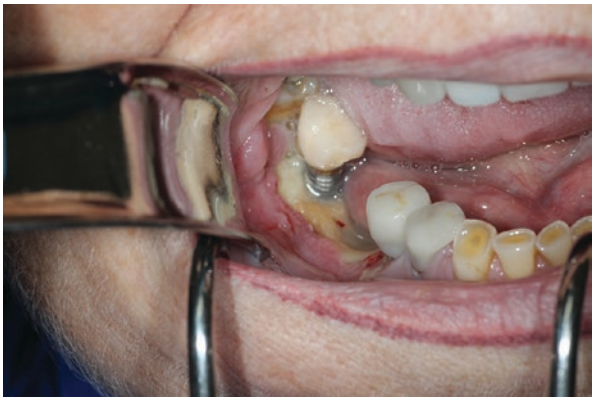

Fig. 14 Stage III DIONJ with exposed bone and osteolysis to the inferior border

a ridge augmentation or site preparation bone graft or if sufficient bone remains, one can proceed to dental implant placements directly.

2.4 Extensive DIONJ Cases in the Osteoporotic Patient

In this author's experience 18% of DIONJ cases in osteoporotic patients are sufficiently extensive so as to require a continuity resection in the mandible or a submucosal maxillary resection and sinus debridement in the maxilla.

In the mandible, the continuity resection defect may be grafted at the time of the resection if there is little or no active infection present and there is sufficient soft tissue to cover the graft. If an immediate bone graft is not feasible due to an absence of soft tissue, this author stabilizes the defect with a 3.0 mm titanium reconstruction plate and accomplishes a free vascular fascio-cutaneous flap to replace any lost soft tissue of mucosa or skin. If an immediate bone graft is not feasible due to an active infection but has sufficient healthy soft tissue, this author places a 3.0 mm titanium plate and closes the soft tissue directly without grafting. In either case, the tissue be can be bone grafted once it is healed and mature, usually in 3–4 months (Figs. 14, 15, and 16).

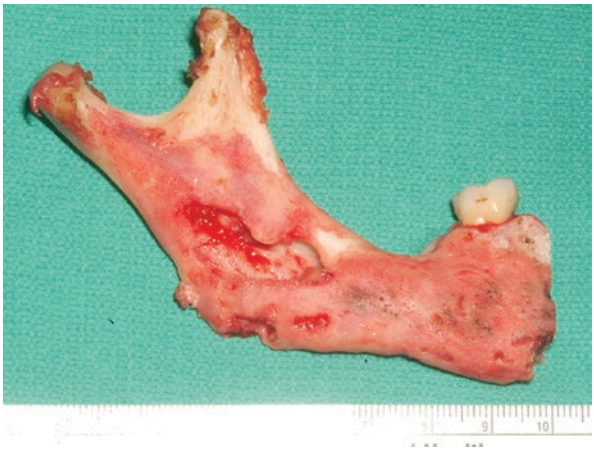

Fig. 15 Resected specimen of Stage III DIONJ

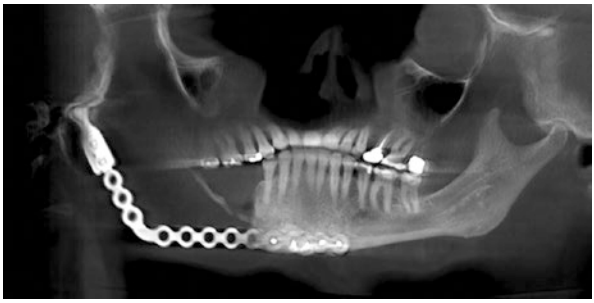

Fig. 16 Postoperative radiograph of titanium plate reconstruction 12 years posts resection

Bone grafting options are up to the training and experience of the oral and maxillofacial surgeon and include autogenous cancellous marrow grafts, in situ tissue engineered grafts of bone marrow aspirates or PRP together with rhBMP-2/ACS 1 mg/1 cm of continuity defect and freeze dried cancellous allogeneic bone particulate, or free vascular osseocutaneous grafts. Such grafts of either type will be sufficiently mature to place dental implants by 6 months. In the maxilla, resections mostly take the form of removing the maxillary sinus floor and debriding the infected sinus membrane as well as numerous infected sinus mucoceles and polyps. In such cases, advancing the local buccal fat pad into the sinus floor and suturing it to the palatal mucosa and the buccal plate of the maxilla through trans osseous bur holes enhances the success of the procedure. The buccal fat pad has a pedicled blood supply which promotes healing and serves as one of two layers in the closure. The other layer being the advanced overlying mucosa (Figs. 17, 18, 19, 20, and 21).

In these maxillary cases, it is not usually feasible to graft immediately due to the presence of infections and the large sinus opening. However after 2 months, the tissue is sufficiently healed for grafting. A sinus lift augmentation graft is feasible at this time where the buccal fat pad is lifted along with a regenerated sinus membrane

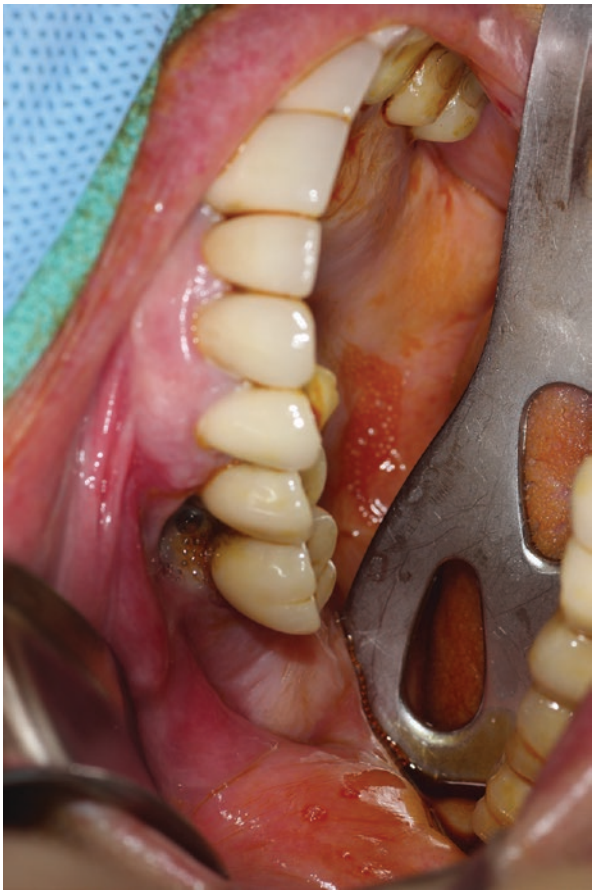

Fig. 17 Stage III DIONJ: Exposed bone in posterior maxilla with sinus involvement

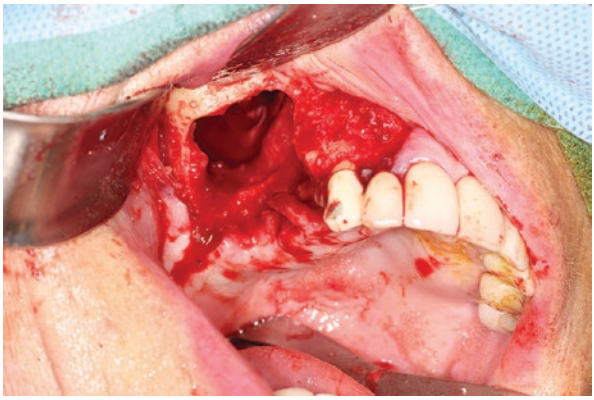

Fig. 18 Caldwell-Luc entry for debridement of necrotic bone and infected sinus membrane

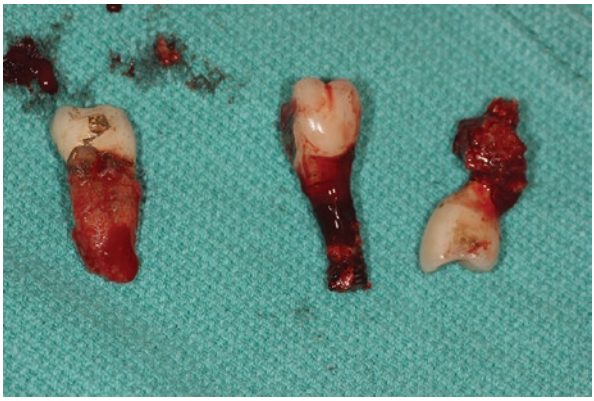

Fig. 19 Teeth, implant, and necrotic bone from sinus debridement in DIONJ

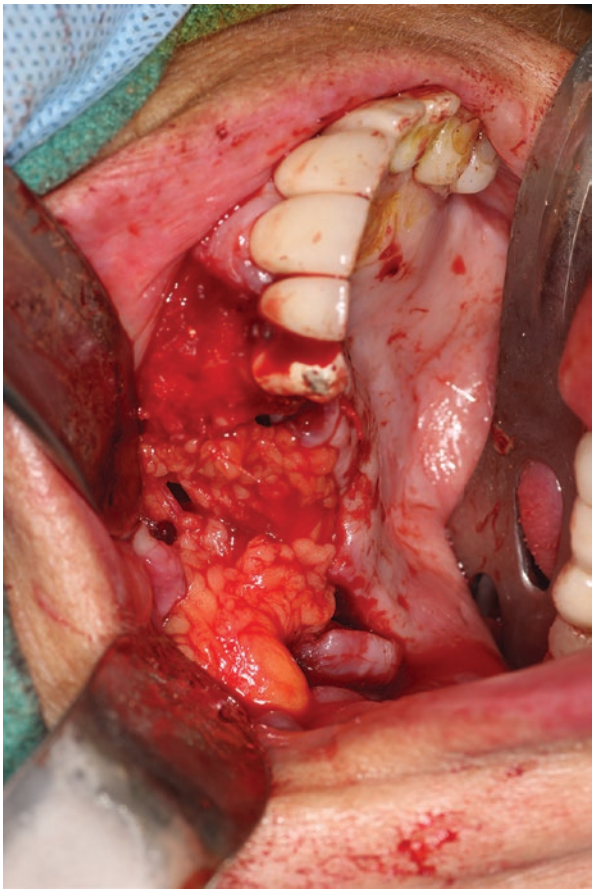

Fig. 20 Advanced buccal fat pad for one of two layers of closure of the Cadwell-Luc entry

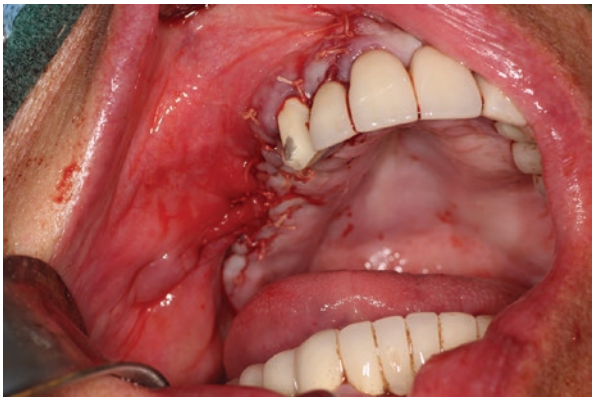

Fig. 21 Advanced mucosa creates a double layer closure over the Caldwell-Luc entry

so that a bone graft can be placed between the lifted buccal fat pad and the oral mucosa. Once again the bone graft is allowed to mature for 6 months before implants can be placed.

2.5 Safety of Dental Implants in Patients Taking Subcutaneous Denosumab for Osteoporosis

The principles and practice of preventing and treating cases of DIONJ caused by subcutaneous denosumab are identical to those just described for oral bisphosphonates with only a few but important caveats. Because denosumab inhibits and kills the developing osteoclast in the bone marrow, the circulation, and at the resorption site it depletes osteoclast reserves. Cases of DIONJ in the osteoporotic patient caused by denosumab will occur sooner and will be more severe [14]. In fact, DIONJ cases have occurred after just three doses of subcutaneous denosumab 60 mg every 6 months. However, due to the 26 day half-life of denosumab, implant complications can be averted using a drug holiday of only 4 months prior to the procedure followed by 3 months after the procedure. This represents a shorter drug holiday than that of bisphosphonates and is only a minor variation from the every 6 month protocol used for denosumab in osteoporotic patients. It applies to preventing DIONJ in implant surgeries as well as treating existing DIONJ from denosumab given at 60 mg every 6 months.

It is important to note that some physician's feel that a rebound affect occurs once denosumab is discontinued which may make osteoporosis worse. Although the studies that suggest this are subject to Drug Company supported bias, the oral and maxillofacial surgeon should be aware of this [15]. This rebound fracture effect in osteoporotic woman after denosumab is more likely due to the downregulation of marrow stem cells and osteoprogenitor cells which also happen to have RANK receptors. The above recommended 4 month drug holiday before placing dental implants followed by a 3 month drug holiday afterward averts this concern.

Another important note is that many patients will relate that they are currently receiving subcutaneous denosumab for osteoporosis but had previously received a bisphosphonate usually alendronate. This should raise a concern for the oral and maxillofacial surgeon that these patients are at an even higher risk for DIONJ than if either class of drug was taken alone. In these patients, the bone is loaded with the bisphosphonate but the bone marrow is producing sufficient osteoclasts to remodel and rebuild bone so as to prevent DIONJ. The addition of a RANK ligand inhibitor such as denosumab rapidly depletes the bone marrow osteoclast precursors often causing a rapid onset of DIONJ. In such cases, a request is made to the prescribing physician for a full 9 month drug holiday as for a pure bisphosphonate-treated patient followed by a 3 month continued drug holiday. Also relate to the prescribing physician, the synergistic damaging effects of a bisphosphonate followed by a RANK ligand inhibitor such as denosumab and provide a copy of the relative risk scale for each drug noted in this text.

Case Example #4:
An otherwise healthy 80-year-old woman with osteoporosis requires the removal of 4 teeth and requests immediate implant placement. She has been treated with vitamin D and calcium for 15 years and is currently taking raloxifene for osteoporosis.

Recommended Course of Action:

1. Relate to the patient that neither vitamin D and calcium nor raloxifene pose a risk for DIONJ.
2. There is no need to request a drug holiday.
3. Proceed with the removal of teeth and implant placement including socket grafting or peri implant grafting as required.

Example #5:
A 55-year-old woman with controlled hypertension and controlled Type II diabetes requires six implants in the maxilla together with bilateral sinus lift augmentations. She relates that she has been using denosumab for 3 years for osteoporosis. You ask her about the last dose to which she responds that it is due later this month.

Recommended Course of Action:

1. Realize that well controlled type II diabetes and controlled hypertension pose no contraindication to dental implant surgery.
2. Calculate that this patient received six doses of denosumab which places her in the risk category.
3. Realize that her denosumab 60 mg every 6 months protocol now represents a drug holiday in excess of the recommended 4 months.
4. Request that the prescribing physician postpone the next denosumab injection until 3 months after your procedure.
5. Proceed with the planned procedure once the prescribing physician concurs with postponing the next planned denosumab injection.

Example #6:
A 74-year-old otherwise healthy woman who has received 4 years of denosumab for osteoporosis but now has a severely painful cracked tooth #29 and a draining abscess. She received her last dose 1 month ago.

Recommended Course of Action:

1. Realize that this patient received eight doses of denosumab and is therefore at risk for DIONJ.
2. If the pain can be reduced to a tolerable level with antibiotics (either doxycycline 100 mg once daily or amoxicillin 500 mg three times daily and analgesics), defer the tooth removal for another 3 months as a drug holiday.
3. If the pain is too severe and cannot be reduced by antibiotics and analgesics, provide informed consent of a high risk for DIONJ and remove the tooth.
4. In either situation, defer implant placement due to the risk for DIONJ and the presence of infection.
5. If DIONJ develops request a 4 month drug holiday from the prescribing physician and consider a sequestrectomy or local alveolectomy.
6. If the socket heals without exposed bone, proceed with implant placement or bone grafting as indicated under the 4 month drug holiday protocol.

Example #7:
A 64-year-old osteoporotic woman had a dental implant placed by another provider who was unaware that the patient had been receiving denosumab 60 mg subcutaneous every 6 months for the past 3 years. Her last dose was last week. She now has exposed bone about the implant with a slight purulent exudate. The implant is clinically stable (Fig. 22).

Recommended Course of Action:

1. Realize she already has DIONJ and requires treatment.
2. Take a baseline CBCT or a panoramic film to assess for the amount of bone involved.
3. Proceed to request a drug holiday of 4 months and prescribe either of the two recommended antibiotics.
4. After 4 months look for radiographic evidence of an involucrum and proceed to remove the implant and the necrotic bone.
5. If the infection was well controlled during the drug holiday consider socket grafting or ridge augmentation otherwise stage it for about 3 months to resolve any residual infection (Figs. 23 and 24).
6. Continue the drug holiday for 3 months after the procedure and forward the list of alternative osteoporosis drugs related to risk for DIONJ to the prescribing physician.

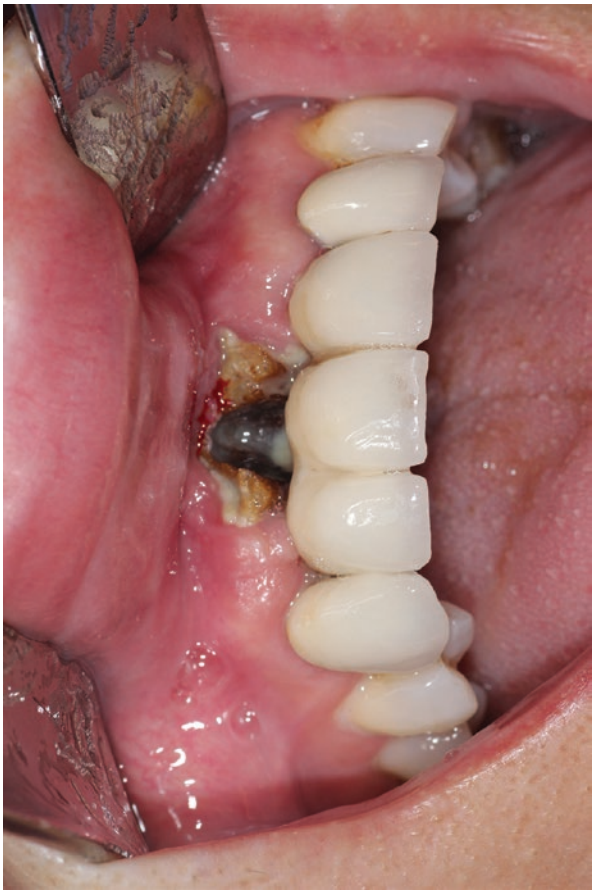

Fig. 22 Exposed bone DIONJ about an implant placed without an appropriate drug holiday

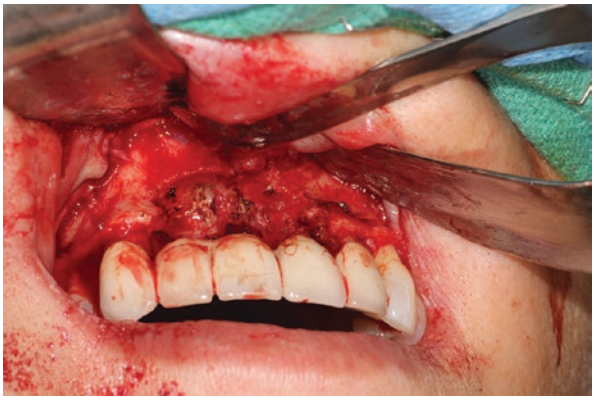

Fig. 23 Sequestrectomy and removal of teeth within necrotic bone after an appropriate drug holiday

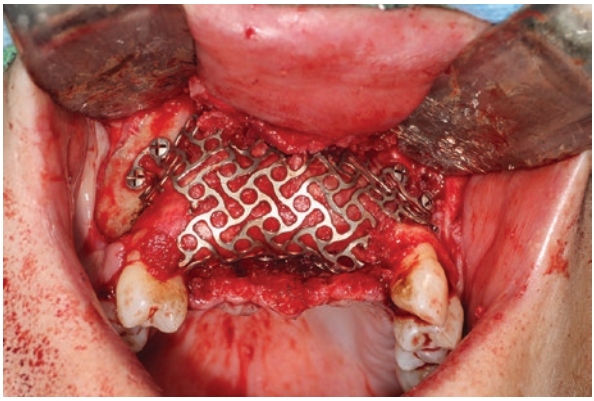

Fig. 24 Bone graft reconstruction of anterior maxillary alveolar defect from DIONJ surgery

3 Section II: The Cancer Patient with Bony Metastasis and/or Hypercalcemia of Malignancy

The cancer patient presents a greater risk for DIONJ and a greater challenge in preventing it and/or treating it. This is partially due to the comorbidity of the cancer itself and the concomitant chemotherapy drugs that they receive. While neither of these comorbidities cause DIONJ, they do promote it to occur sooner and be more extensive if the patient is also taking one of the following drugs known to cause DIONJ in metastatic cancer patients.

3.1 Drugs Known to Cause DIONJ in the Metastatic Cancer Patient

There are several well-known cancers that metastasize to bone and for which physicians treat with specific drugs that are known to cause DIONJ. These cancers include breast cancer, prostate cancer, multiple myeloma, lung cancer, and renal cancer and more rarely lymphomas in bone. The prudent clinician is recommended to specifically include these cancers in their medical history forms. The drugs known to cause DIONJ in the metastatic cancer patient and the common cancer for which they are used are listed in Table 1 and are:

1. Zoledronate 4 mg IV once month. Used in breast cancer, multiple myeloma, prostate cancer, lung, and renal cancer. Zoledronate is a potent bisphosphonate that works by killing and/or inhibiting osteoclasts mostly at the resorption site therefore inhibiting bone remodeling and renewal [15].
2. Denosumab 120 mg SC once monthly. Used in breast cancer, multiple myeloma, prostate cancer, lung cancer, and renal cancer. Denosumab is a monoclonal

antibody against RANK ligand. Its action kills developing osteoclasts in the bone marrow the circulation and mature osteoclasts at the resorption sire [16].
3. Bevacizumab. It is used exclusive in lung cancer patients and is often used together with either Zoledronate or denosumab. It is a monoclonal antibody against vascular endothelial growth factor (VEGF) and thereby inhibits new capillary formation [17].
4. Sunitinib . It is used almost exclusively in renal cancer patients and may be used together with either Zoledronate or denosumab. Sunitinib is a tyrosine kinase inhibitor which downregulates several growth factors [18]. However, its main DIONJ producing property is its effect on VEGF and is therefore similar to bevacizumab.

4 Prevention of DIONJ in Metastatic Cancer Patients Taking Drugs Known to Cause DIONJ and Requiring Implants

4.1 Prevention Before Beginning Treatment

The best time to place dental implants in a cancer patient is before starting treatment with any of the above drugs. If the need for any of these drugs can be deferred for 3 months their effect on osteointegration is significantly lessened and the process of osteointegration is well on its way. Nevertheless the clinician should provide a consent form that states that a risk for DIONJ is still present due to the higher doses particularly of Zoledronate and denosumab in these patients. After a dental implant is placed and osseointegrates in a metastatic cancer patient with this 3 month deferment who then goes on to receive any of this group of drugs, a risk for DIONJ exists but is no higher than that of a native tooth or a preexisting implant.

4.2 Avoiding Dental Implant Complications During Treatment with Drugs Known to Cause DIONJ in Metastatic Cancer Patients

The risk for complications of DIONJ when implants are placed during active treatment with this group of drugs is significant and is therefore not recommended in other than selected patients and even then with informed consent as to the risk (Fig. 25).

Due to the 11.2 year bone half-life of Zoledronate and the rapid high loading of bone, dental implants during this time are rarely accomplished. The author has found that the patient who has been discontinued (a drug holiday) from Zoledronate for 8 years or more (i.e., more than one half-life) can have dental implants placed with only minimum risk for DIONJ. However, this is an uncommon clinical history and does not apply if denosumab was substituted for Zoledronate.

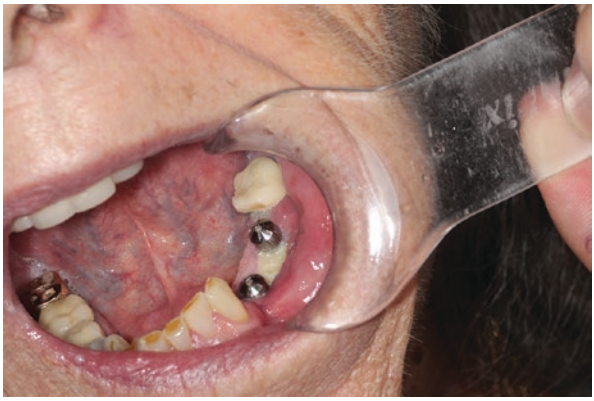

Fig. 25 Dental implants in exposed bone soon after placement in a patient treated with Zoledronate for metastatic breast cancer

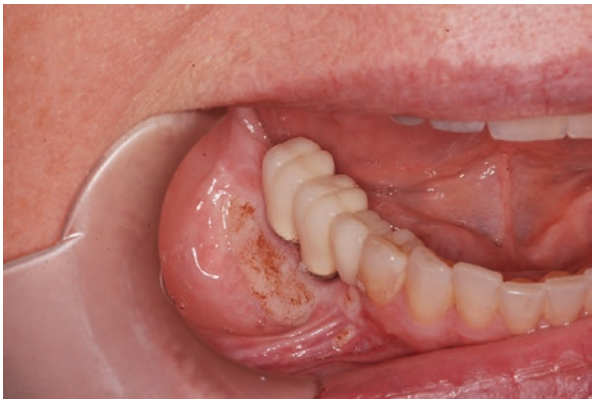

Fig. 26 Successful implants and restorations from implants placed in a denosumab treated patient using a drug holiday of 4 months prior and 3 months after the placement

Another select patient is one who is in remission from their cancer and was only on denosumab, bevacizumab, or sunitinib with no previous treatment with Zoledronate. Due to the short half-life of each of these drugs implant placement with a minimal risk for DIONJ can be accomplished with a 4 month drug holiday prior and a continued 3 month drug holiday after implant placement (Figs. 26 and 27).

It should be noted that dental implants in both the osteoporotic patient and the metastatic cancer patient require precise restorations that avoid traumatic occlusion or excessive occlusal loads. This is due to the effects of Zoledronate and denosumab on osteoclast-mediated bone remodeling and bevacizumab and sunitinib on capillary ingrowth. Bone remodeling and renewal is part of the homeostasis related to the interface of teeth and dental implants to bone. Excessive occlusal loads will exceed the bones' ability to adjust and predispose the bone to become nonviable.

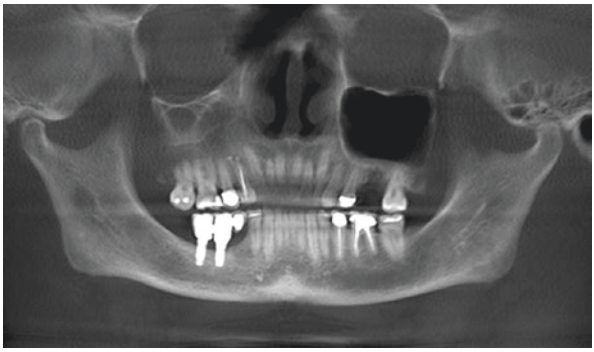

Fig. 27 Osseointegrated implants in the patient presented in Fig. 26

4.3 Treating Complications of Dental Implants Placed in Metastatic Cancer Patients Who Have Received Drugs Known to Cause DIONJ

Complications from dental implants placed into patients with metastatic cancer and who have also received a drug known to cause DIONJ will present with more than just a failing implant. They will have necrotic bone from DIONJ. Some of them will be extensive requiring either an alveolar bone resection, a Caldwell-Luc extensive sinus debridement if in the maxilla or a continuity defect if in the mandible. In such cases, a drug holiday of 4 months before and 3 months after are useful in patients who have received denosumab, bevacizumab, or sunitinib but not Zoledronate due to its 11.2 half-life in the bone.

If the clinical and radiographic examination shows that the necrotic bone is limited to the alveolar bone, an alveolar resection is indicated. Remarkably implants within exposed necrotic bone are often stable and asymptomatic. In such cases, it is reasonable to leave a functional implant in the necrotic bone and maintain with an ongoing antibiotic to reduce secondary infection (Fig. 28). In cases where an alveolectomy is required one should undermine the adjacent mucosa to gain a primary closure. The addition of platelet-rich plasma will also assist the healing process and is recommended. However, the clinician should remember that rhBMP-2/ACS is contraindicated in patients with active cancer which applies to this location is such patients (Figs. 29, 30, 31, and 32).

A relatively frequent presentation is Stage III DIONJ in the posterior maxilla with a concurrent sinus infection. In this type of presentation, a high yield surgery for resolution of the DIONJ involves removing the implants and the necrotic bone as well and accomplishing a thorough sinus debridement via a Caldwell-Luc entry. Here advancing the local buccal fat pad into the floor of the sinus and suturing it to the palatal mucosa and thorough transosseous burr holes in the anterior wall of the maxilla enhances the healing. Once again,

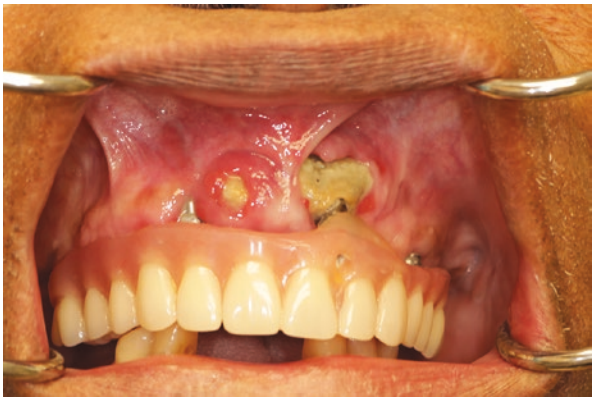

Fig. 28 Although these implants are in necrotic bone from DIONJ, they are stable and functional. Theses may be left to support function and treated for secondary infection

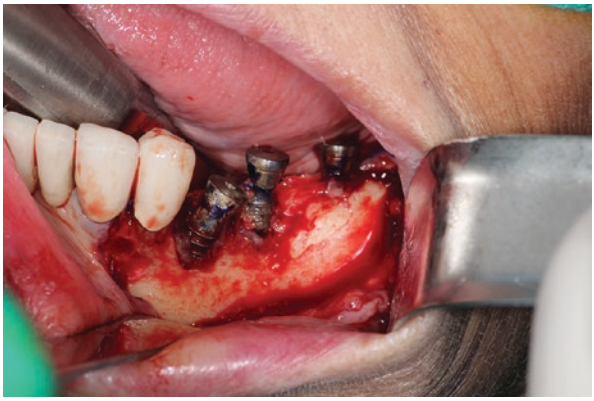

Fig. 29 Necrotic bone from DIONJ with failing implants

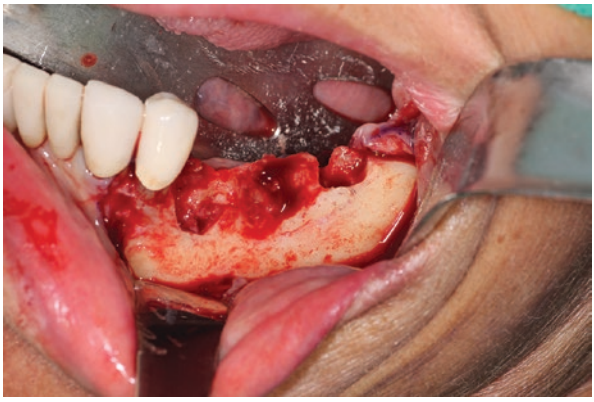

Fig. 30 After removing the failing implants, the residual alveolar bone should be removed to the apical level of the sockets

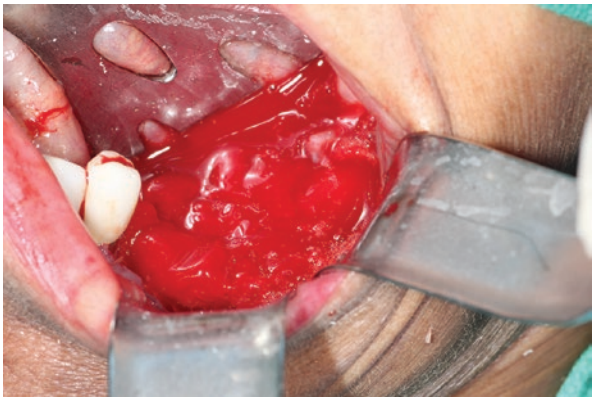

Fig. 31 Platelet-Rich Plasma (PRP) will assist the healing of an alveolectomy for DIONJ

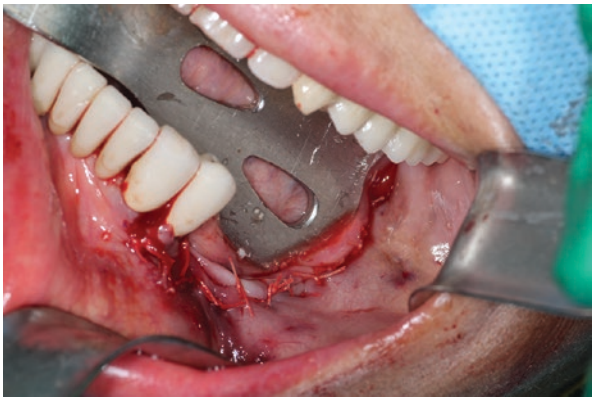

Fig. 32 Undermining to gain a primary closure over the alveolectomy site

platelet-rich plasma is also a good adjunct and an undermining of the buccal mucosa to gain a two layered closure is recommended (see example case for osteoporosis Figs. 17, 18, 19, 20, and 21).

Less frequent cases of Stage III DIONJ around dental implants in the mandible will require a continuity resection. The clinician should note that reconstructing mandibular continuity defects in metastatic cancer patient is problematic. This is due to the actual presence or potential presence of metastatic cancer in the donor bone and that rhBMP-2/ACS is contraindicated in such patients. Therefore, a 3.0 mm rigid titanium mandibular reconstruction plate that gains continuity often becomes the permanent reconstruction. Therefore, the clinician should approach the mandible from a wide extraoral approach and plan for four or more bicortical

locking screws on both the proximal and distal segments. Although DIONJ rarely extends to threaten the condyle, such situations that require a disarticulation resection should be planned for six to eight bicortical locking screws on the distal segment. Here, a virtual planned fossa reconstruction is helpful to maintain the metal condylar replacement in the fossa.

Example #8:
A 70-year-old woman with metastatic breast cancer has six remaining non-restorable anterior mandibular teeth. She is a candidate for an "all in four" dental implant protocol. However, she is planned to start Zoledronate next month. She is currently taking Faslodex and Taxotere. Her oncologist requests a "dental clearance."

Recommended Course of Action:

1. Realize neither Faslodex nor Taxotere have a significant impact on alveolar bone remodeling/renewal or osseointegration.
2. Request that the oncologist defer Zoledronate for 4 months in order to provide a dental clearance (Note! Most all will agree with this because the metastatic foci are slow to expand).
3. Remove the six anterior teeth and level the bone down to just apical to the apical extent of the sockets (This is recommended because the alveolar bone is the most vulnerable bone for drugs such as Zoledronate). Place the four implants as per the "all on four" protocol and cover screws for a planned two stage protocol.
4. Uncover "second stage" the implants at 6 months being careful to excise only the soft tissue over the cover screw.
5. Recommend against a screw retained prosthesis so that the patient can maintain a judicious oral hygiene about the implants. Milled dentures, Hader Bar retained, or swing lock designs will allow the patient better access to prevent peri implantitis that in the upcoming months that may risk DIONJ with the anticipated treatment with Zoledronate.

Example #9:
A 76-year-old with multiple myeloma has mobile implants within necrotic bone in the anterior maxilla and is currently on denosumab 120 mg monthly. He has received eight doses to date. The last dose was yesterday. Of the six dental implants in place, four are clinically stable and are retaining his full maxillary prosthesis. Two dental implants are within exposed necrotic bone. The implants and the bone are slightly mobile. There is a swelling and pus about the mobile bone implant complex.

Recommended Course of Action:

1. Prescribe antibiotics to control the secondary infection. The author would use either doxycycline 100 mg once daily or amoxicillin 500 mg three times daily indefinitely until a debridement surgery is accomplished.
2. Obtain a cone-beam CT scan or panoramic film to fully assess the quality of the bone.
3. Request a 4 month drug holiday from the oncologist.
4. Anticipate that the drug holiday will confer a greater mobility of the exposed bone so that it will delineate necrotic bone from local viable bone.
5. Accomplish a sequestrectomy of the necrotic bone and the implants within it.
6. As long as the remaining implants are stable and can support a prosthesis retain them even if there is exposed bone present. Continue the antibiotic regimen to resist secondary infection that may cause an extension of the DIONJ and loss of the remaining implants.
7. Inform the oncologist of the situation where further antiresorptive therapy would likely result in the loss of the remaining implants and bone to a state of oral disability.
8. Monitor the patient afterward on an every 4 month basis.

Example #10:
A 79-year-old woman with metastatic breast cancer has failing implants, pain, and infection in the posterior mandible (Fig. 33). She is considered in remission. However, she has received 24 doses of Zoledronate. The oncologist has recently discontinued the Zoledronate. Her cone-beam CT scan notes extensive osteolysis and the clinical examination notes a cutaneous fistula (Figs. 34 and 35).

Recommended Course of Action:

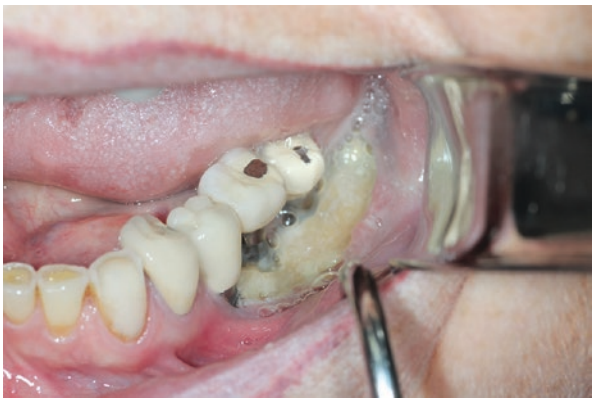

Fig. 33 DIONJ from Zoledronate for metastatic breast cancer

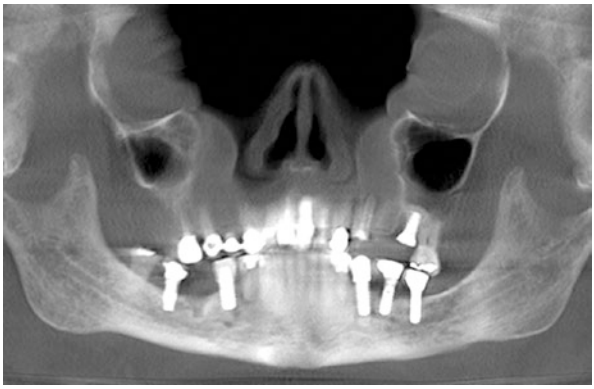

Fig. 34 Implants within necrotic bone due to Zoledronate with extensive osteolysis

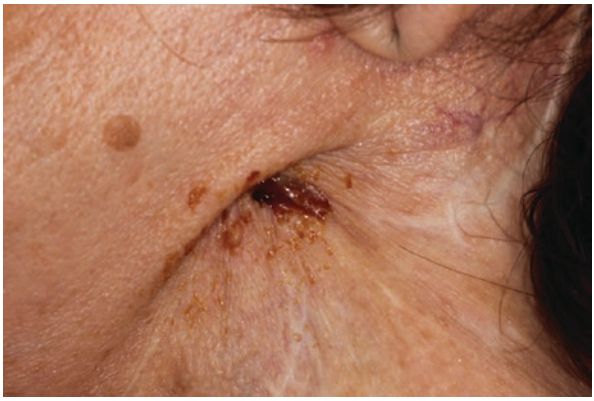

Fig. 35 Draining fistula indicative of active infection. Skin contraction indicative of chronicity

1. Realize that due to the 11.2 year half-life of Zoledronate in bone a drug holiday is not useful.
2. Prescribe antibiotics of either doxycycline 100 mg once daily or amoxicillin 500 mg three times daily. Also, consider adding metronidazole 500 mg three times daily for a limited 10 day course.
3. Plan on a continuity resection with a titanium plate reconstruction (Figs. 36 and 37). Also accomplish radiographs of each fibula as metastatic breast cancer rarely metastasizes to the fibula and a CT angiogram to assess the vasculature for a potential microvascular fibula reconstruction (Fig. 38).
4. During the surgery tag and advance the genioglossus muscle to the titanium plate and/or the fibula to support the airway. Consider a delayed extubation or a tracheostomy as well.

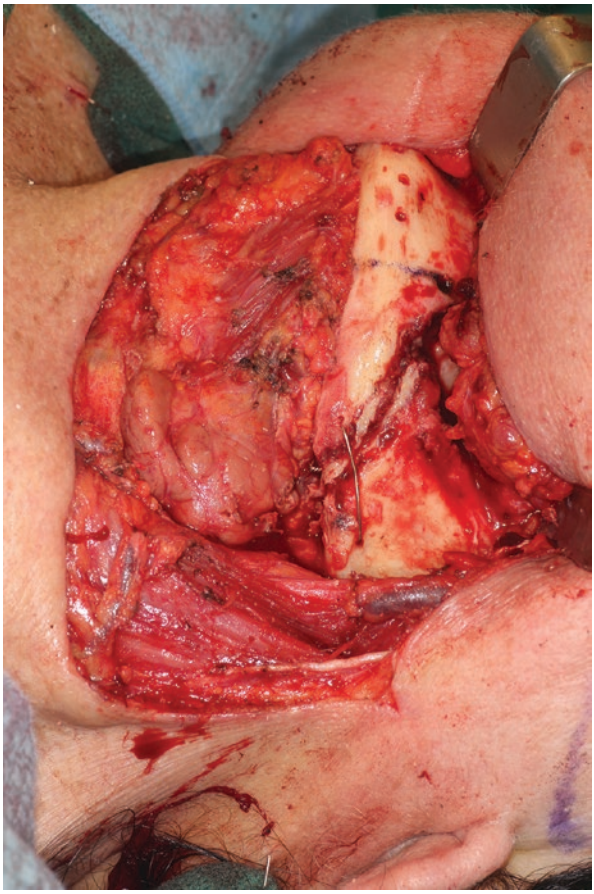

Fig. 36 After implants and granulation tissue were removed, a pathologic fracture was evident

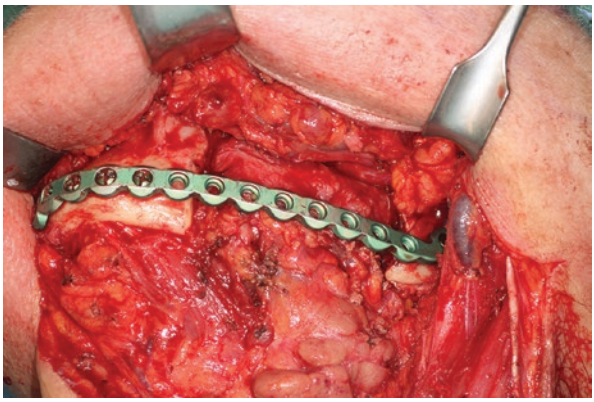

Fig. 37 Titanium plate was used to re-establish continuity and stability after the resection

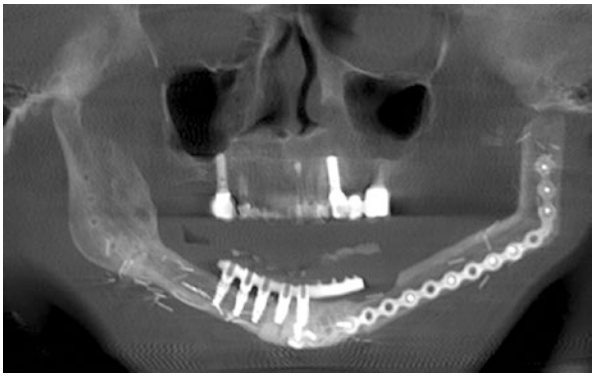

Fig. 38 In severe DIONJ cases in patients without multiple myeloma, a free vascular fibula graft followed by dental implant restorations is possible provided radiographs and/or scans rule out metastatic deposits in the fibula

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Complications in the Atrophic Mandible

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and Guilherme dos Santos Trento

1 Introduction

Alveolar ridge atrophy is not always related to advanced age. In developing countries, due to socioeconomic conditions, many young patients prematurely lose their teeth and develop early bone atrophy. However, in the normal situation, the majority of severe vertical and horizontal bone losses occurs with advanced age [1].

It is estimated that in 2050 the world population will reach nine billion people, not only due to birth rates, but also because of the increased life expectancy and reduction in mortality rates [1]. According to Ortman et al. [2], the estimated elderly population (over 65 years of age) in the United States will double in the next 30 years, while in other countries it will exceed 37% in 2050.

One study considering the first decade of the years 2000, in Brazil, the largest country in South America, showed a considerable decrease in the needs for prosthetic rehabilitation among adolescents (52% reduction) and adults (70% reduction) [3]. Although the prevalence of dental loss and edentulism have been reduced throughout the years [4, 5], it is very far from being completely erradicated [1]. Moreover, the total amount of edentulous persons is decreasing in many developed countries, but not in developing countries. This is attributed to the high prevalence of periodontal disease and caries. Traumatic dental and bone losses may also happen. So, osseous reconstruction and dental implants will keep on being necessary treatment options [1, 4, 6].

After total loss of teeth, the maxilla and mandible present different patterns of bone resorption, which were well described by Cawood and Howell, in 1998 [7].

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Table 1 Soft tissue and bone-related complications

Soft tissue	Perforation/laceration Inability to properly mobilize the soft tissue Nerve damage Hemorrhage Hematoma/seroma Dehiscence Flap necrosis Infection
Bone	Osseointegration failure Implant loss Graft resorption Mandibular fracture Medication-related osteonecrosis

They identified a mainly horizontal resorption pattern, in the anterior maxilla and a mainly vertical pattern in the posterior maxilla. In the mandible, resorption occurs mainly vertically, primarily affecting bone height. The mean loss of bone is 4–6 mm in the first year and then approximately 0.4 mm yearly. Those changes are related to anatomical, metabolic, functional, and prosthetic factors. Usually, the basal bone does not undergo significant changes, while the alveolar ridge suffers both vertical and horizontal bone loss. The stage of the resorptive process varies according to the jaw involved, region and cause of tooth loss. Anatomical and physiological characteristics make reconstructive procedures in the mandible more critical, especially in the posterior region.

Regarding the mandible, resorption results not only in mechanical weakening, but also in diminished vascularization and reduced blood flow to the bone, which are unfavorable for bone healing and can compromise osseous reconstruction and dental implant survival [8–10]. Adding to those problems, elderly patients frequently present systemic conditions that may interfere in the perioperative care and directly or indirectly influence bone healing [11]. More recently, the widespread use of bisphosphonates has become another complicating factor [12].

Although a high index of success is described in the literature, complications may occur in implant and osseous reconstructive surgery, such as infection, loss of bone grafts, mandibular fracture, nerve injuries and osteointegration failure, among others. The incidence of complications may be as high as 20%. The best way to avoid complications is careful prosthetic and surgical planning [13–15].

Discussion of complications automatically leads to concerns about treatment failure. Some clinical studies show the importance of identifying risk factors related to bone quantity and quality, site and presence of bone grafts, as well as systemic factors, smoking and metabolic diseases, which may lead to complications and treatment failure [16, 17].

The objective of this chapter is to discuss the most common complications associated with rehabilitation of atrophic mandibles, as well as possible prevention and treatment strategies. Complications will be divided into bone and soft tissue occurrences, as shown in Table 1.

2 Soft Tissue Complications

2.1 Incorrect Soft Tissue Manipulation and Dehiscence

In cases of bone atrophy, the soft tissue can become a problem due to the small amount of available keratinized gingiva and thin alveolar mucosa. This may lead to the exposure of implants, grafts, metallic meshes, and biomaterials and result in treatment failures that will promote increase in time, cost and difficulty to complete the treatment.

Primary closure of the soft tissues is necessary to warrant favorable outcomes after implant installation and guided tissue regeneration. To obtain primary closure in the reconstruction of atrophic ridges, the soft tissues have to be carefully reflected and mobilized [18, 19]. Design of the flap, as well as position and length of incisions, should consider the amount of exposure required to perform the procedure and allow for adequate closure, preventing the need for excessive tissue stretching and the risk of closure under tension.

Careful manipulation of the soft tissues in the atrophic areas is necessary to maintain health of the peri-implant tissues at the end of the treatment. Close adaptation of connective tissue and epithelium around transmucosal implant structures is essential to create a barrier against peri-implant infections. Care must be taken to manipulate and preserve the soft tissue at the implant site and to perform soft tissue augmentation when indicated. Flap design must make sure that adequate amount of keratinized gingiva is present in both the buccal and lingual sides of the implant.

Goodacre et al. [20] observed 2–11% of mucoperiosteal perforation during implant installation. That complication may occur during or after the surgical procedure, due to small thickness, insufficient or traumatic mobilization of the soft tissue, or acute trauma by immediate poorly adapted interim prosthesis supported by mucosa. Such lesions may progress with necrosis of the mucosa and result in poorly keratinized tissue around the implants. It may also conduct to exposure and loss of implants and grafts. Perforations and lacerations should be treated intraoperatively, as soon as recognized, by suturing, flap mobilization or insertion of membranes under the mucosal flap. Without proper treatment, perforations may create soft tissue dehiscence postoperatively [20].

Soft tissue dehiscence is also a frequent complication after vertical or horizontal guided bone regeneration (GBR). Here again the most effective preventive measure is precise, atraumatic, and well-planned soft tissue manipulation [21, 22]. Tension-free flap reposition is essential to avoid complications [23]. Releasing incisions in the periosteum are usually necessary to obtain tension-free soft tissue closure. Those should be performed with care to avoid lacerations.

Flap dehiscence after GBR may result from several causes, such as deficient mucosal thickness, failure to obtain complete covering or excessive tension on the repositioned flap; proximity of muscle insertions and mucosal bridles, extensive edema, hematoma or seroma; border necrosis caused by sutures; loose sutures; bone spicules produced by reshaping; bone fragments loose under the periosteum, as well as by cytotoxic and vasoconstrictor substances [24–26]. Moses et al. [27] observed

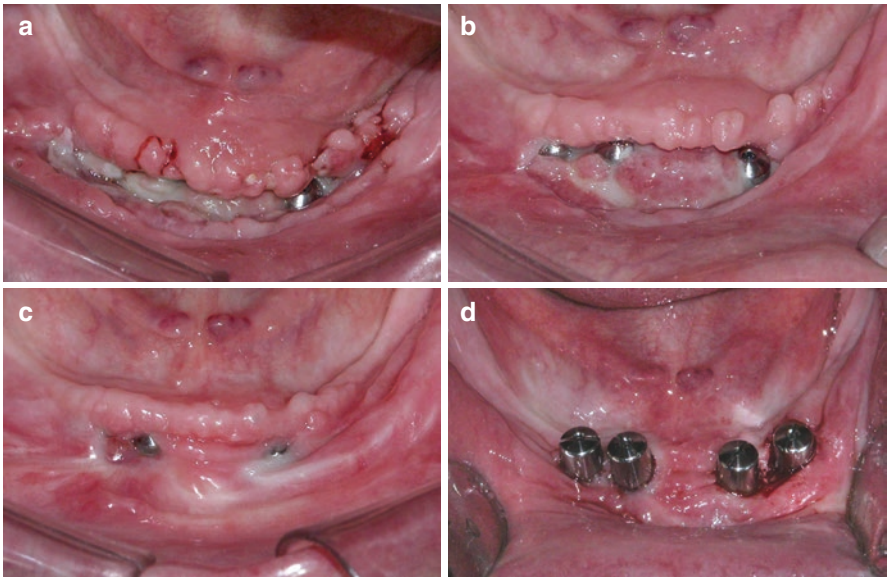

Fig. 1 (**a**) Suture dehiscence in the anterior mandible. (**b**) Granulation tissue during local treatment. (**c**) Epithelization through second-intention healing. (**d**) Insertion of healing screws. (Courtesy of Dr Leandro Benetti, Brazil)

an incidence of 35% of soft tissue dehiscence after treatment of horizontal resorption by GBR, which contributed to a significant decrease in the gain of bone volume.

Small wound dehiscence that occurs during the first 24 h postoperatively can usually be treated by approximation and resuturing of the flap and sometimes by only keeping the area clean, when very small. Dehiscence involving an area greater than 2 mm is considered large and represents a significant problem, especially when occurring more than 48 h postoperatively. In that instance, there is usually need for soft tissue debridement before resuturing of the wound is attempted, but in many cases recurrence of dehiscence happens [28].

More extensive dehiscence, with greater tissue loss, abundant exudate or traumatized wound borders, is usually treated by second-intention healing through cleaning of the wound and chemical control. Usually 0.12% chlorhexidine or oxygen liberating gels are used. The wound will be initially covered by granulation tissue, then followed by epithelization. Normally, a greater amount of fibrous tissue will be present after healing, requiring surgical revision at the moment of prosthetic rehabilitation [29] (Fig. 1). Table 2 lists measures to prevent soft tissue dehiscence.

2.2 Hemorrhage and Hematoma

Hemorrhage and hematoma formation may occur in implant and reconstructive procedures, both during surgery and postoperatively. They may create serious

Table 2 Prevention of soft tissue dehiscence

Correct flap design
Atraumatic manipulation of soft tissue
Maintain/create keratinized mucosa
Aim for primary closure
Avoid perforation/laceration of soft tissue
Correct suturing, without tension
Perform releasing periosteal incisions as necessary
Use of membranes under flap when indicated
Remove bone spicules and fragments
Release interfering muscle insertions and mucosal bridles
Correct adaptation of prosthesis

complications, resulting in urgent situations and requiring reintervention and even hospitalization. In the atrophic mandible, surgical procedures involving the anterior or posterior regions require knowledge of the anatomy, in order to protect surrounding vascular structures and treat vascular complications [30].

Submental, sublingual, and incisor arteries are part of a vascular plexus that provides blood to the anterior mandible and floor of the mouth. Ramifications of those arteries form an important anastomotic plexus. Pigadas et al. [31] described severe bleeding of that plexus after perforation of the lingual cortical plate of the mandible. Bleeding and hematoma formation may result in edema of the tongue, elevation of the floor of the mouth and airway obstruction [32]. This is not a rare occurrence after surgical intervention in atrophic mandibles.

Identification and elimination of the cause of bleeding and implementation of hemostatic procedures through compression, vasoconstriction, cauterization, and local hemostatic agents, will most often be enough to stop the bleeding [33]. Complementary use of antifibrinolytic agents such as tranexamic acid or epsilon aminocaproic acid may be indicated in severe cases, or in patients under suspicion of having unidentified alterations of hemostasis [34].

In the case of hematoma formation, close attention to the possibility of impending airway obstruction is necessary. Significant hematomas may require urgent drainage if compromising airway patency, or if there is suspicion that this will happen (Fig. 2). Smaller hematomas may also require drainage to avoid infection and abscess formation. In either case, drainage may be intra or extraoral, depending on size and location, but it is usually submental. External compressive dressings should be applied [35]. Table 3 shows preventive measures for bleeding complications.

2.3 Nerve Damage

In severely atrophic mandibles, the mental foramen and neurovascular bundle may be exposed over the alveolar crest, complicating surgical access to the mandible and

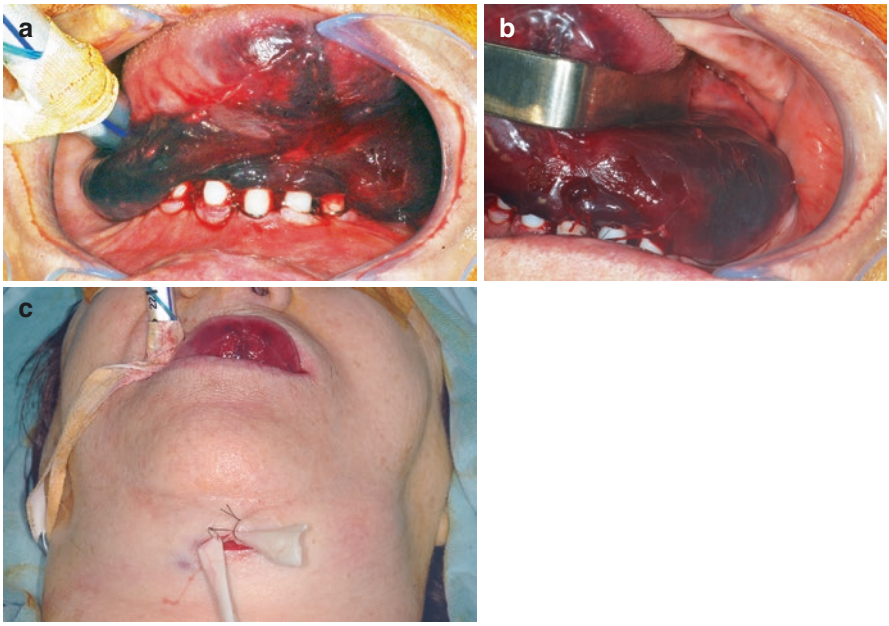

Fig. 2 (**a**) Sublingual hematoma after perforation of the anterior mandibular lingual cortex during ambulatory implant surgery and immediate prosthesis provoking airway obstruction. Frontal view. (**b**) Lateral view of hematoma. (**c**) Emergency submental drainage under general anesthesia

Table 3 Prevention of bleeding complications

Anamnesis and physical examination
Hemostasis testing as indicated
Adaptation of regimen of anticoagulant/antiplatelet drugs
Treatment/preparation of patients with blood disorders by hematologist
Induced controlled hypotension for extensive procedures under general anesthesia
Protection of inferior alveolar neurovascular bundle
Avoid inadvertent perforation of mandibular lingual cortex

exposing the inferior alveolar nerve to potential damage. Thus, care must be taken when incising and reflecting the soft tissue. Damage to the neurovascular bundle during implant/reconstructive procedures can be temporary or permanent. Quantitatively, damage can lead to hyperesthesia, hypoesthesia, or complete loss of sensation. Qualitatively, it can lead to paresthesia or disesthesia [33]. According to Martínez-Rodríguez et al. [36], hypoesthesia and paresthesia are the main sensory alterations encountered after dental implant placement.

A systematic review by Vetromilla et al. [37] verified the incidence of neurosensory alterations in patients submitted to lateralization or transposition of the inferior alveolar nerve, to allow implant insertion. Incidence rates were 3.4% for nerve lateralization and 22.1% for transposition. This was attributed to the fact that in nerve

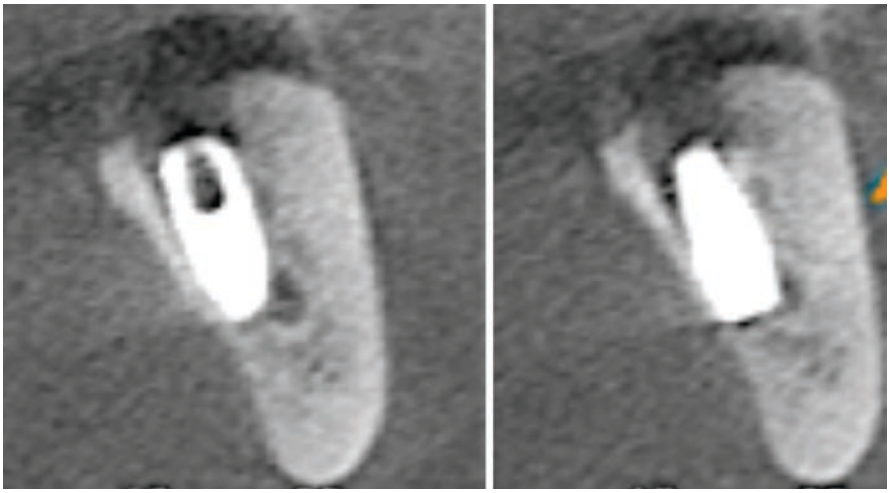

Fig. 3 Implant impinging on inferior alveolar nerve in a patient complaining of hypoesthesia

transposition the neurovascular bundle is removed from the foramen, which results in greater surgical manipulation and trauma. Fortunately, the availability of short implants has reduced the need for vertical grafting and for nerve manipulation for rehabilitation of the posterior mandible [38].

Neurovascular damage is usually related to the inferior alveolar nerve and less frequently to the lingual nerve. Careful surgical planning can avoid this ocurrence [39]. The nature of the damage defines duration and reversibility of the condition. Compression by edema or hematoma and excessive stretching of the nerve during flap retraction are usually reversible. The literature describes an incidence of temporary disturbances of the inferior alveolar and lingual nerves varying from 0.26 to 8.4% and 0.1 to 22%, respectively. The incidence of permanent deficit varies from 0.3 to 0.9% for both nerves [37].

Permanent damages during this kind of procedure occur basically by direct surgical trauma, due to perforation of the mandibular canal or complete nerve rupture. Compression by the implant may cause less favorable or even irreversible damage to the nerve (Fig. 3), regarding adequate recovering [40, 41]. In relation to implant placement, the disturbance caused by positioning the implant close to the nerve is variable. If it is diagnosed early and the implant immediately removed, sensation may return. On the other hand, direct damage to the inferior alveolar or mental nerve during reconstructive procedures frequently causes permanent deficits, with hyperesthesia in some cases [42].

Treatment of neural trauma depends on the extent of the damage and the neurological symptoms described by the patient and may involve medications and/or surgery [33]. Early physical therapy may be helpful. Corticosteroids or non-steroidal

anti-inflammatory drugs (NSAIDS) are frequently recommended for all patients with neural trauma [43, 44]. Misch and Resnik [45] recommend the use of steroids associated with high dosage of NSAIDS, suggesting that steroids may prevent neuroma formation. However, the high potential of gastrointestinal side effects with that association has to be considered, even with the association of gastric protectors.

In the case of hypoesthesias or paresthesias, treatment with vitamin B complex or ribonucleotides may be indicated. Vitamins B1, B6, and B12 are thought to have neuroregenerative properties. Vitamin B is essential for the synthesis of nucleoproteins and myelin and thus for the process of nerve regeneration. Ribonucleotides participate on the biosynthesis of phospholipids and glycopeptides, which are encountered in high concentrations in peripheral nerves [46].

The effect of low intensity laser therapy (LLLT) in peripheral nerves has been tested in several studies. Although a few articles validate the use of LLLT, most human studies continue to present poorly favorable or indifferent results about its use [47, 48]. Miloro and Criddle [49] did a prospective, double-blind, randomized and controlled study and concluded that there is need for more clinical studies about the use of LLLT in oral and maxillofacial neural lesions.

In the case of hyperalgesia and dysesthesia, pharmacological therapy is indicated and should be instituted early. The drugs available are tricyclic antidepressants, anticonvulsants, serotinin, and norepinephrine recapture inhibitors, local anesthetics, topical medications, and opioids [46].

When the nerve is ruptured, immediate neurorrhaphy is indicated if feasible [50]. In severe cases, when the patient cannot withstand or control symptoms, several microsurgical procedures have been employed to treat nerve trauma secondary to implant placement, such as external decompression, internal neurolysis, neuroma excision, neurorrhaphy, and nerve grafting [51]. According to Pogrel [50], almost 50% of patients submitted to microsurgical repair presented improvement of their symptoms. Patients experiencing prolonged pain and sensory alteration who demonstrated little or no response to conservative treatment should be considered for surgical repair. However, they must be informed about their chances of success and risks of the surgical treatment [52]. Table 4 brings preventive measures for neural trauma.

Table 4 Prevention of nerve damage

Careful planning of reconstruction
Precise location of inferior alveolar neurovascular bundle and mental foramen
Precise determination of implant length
Careful flap elevation and use of bone cutting instruments in the lingual surface of retromolar area
Avoid inferior alveolar nerve lateralization/transposition when possible
Use piezosurgery when nerve lateralization/transposition are necessary

2.4 Infections

As discussed above, atrophic mandibles are frequently associated with elderly patients. Reduction of the physiological reserve and local vascularization, secondary to advanced age and bone atrophy, facilitate or aggravate infectious processes, especially those related to metallic implants [1, 8, 9, 11].

Infection is the most frequent factor that contributes to the failure of oral rehabilitations [53]. Harris and Richard [54] showed that Staphylococcus aureus can adhere to titanium surfaces and it is seldom detected in oral infections. Its colonization of biomaterial surfaces results in infectious processes of difficult treatment [55], which will require removal of the implanted biomaterial. Moreover, uncontrolled infection may enhance bone loss and reduce even further the available bone, complicating future reconstructive procedures.

One of the important points to prevent infection is to control or eliminate systemic diseases and conditions, such as nutritional deficits and metabolic diseases. Poor nutrition, smoking, uncontrolled diabetes, autoimmune inflammatory disease, advanced chronic renal or hepatic disease, and the use of immunosuppressive drugs are examples of situations that predispose to postoperative infections [16, 20]. Although this may not be as important as it is for temporomandibular joint prosthetic reconstruction [56], it is advisable to treat systemic infectious processes, such as skin, respiratory, and urinary tract infections, prior to osseous reconstruction and implant installation.

Infections mainly occur in the early postoperative period and are frequently secondary to intraoperative bacterial contamination, intraoral exposure of the implant or graft, or to the lack of proper postoperative care by the patient [57–59]. In healthy patients, correct surgical technique and careful tissue handling are the most important factors to prevent infection [55]. That depends on the surgeon, but it actually also involves the whole surgical team. Every surgical intervention requires local measures that should be followed to avoid complications. Proper hygiene of the surgical wound, relative repose, correct diet, and use of well-adjusted prosthesis, which will not traumatize the operated area, are essential for the prevention of infection. Correct dosage and schedule for the prescribed medications are also important [60]. To reduce contamination by oral flora, prior to implant and ridge reconstructive surgery, preoperative antisepsis with 0.12% chlorhexidine mouthwash is recommended [61, 62].

Although the incidence of infection after implant surgery is low, the need for antibiotic prophylaxis is still discussed. Binahmed et al. [63] compared the use of a single dose of antibiotics as opposed to maintaining antibiotic therapy in the postoperative period. They did not find any statistically significant difference between groups and concluded that prolonged antibiotic therapy presents no advantages over single dose prophylaxis. Kashani et al. [64] reached the same conclusion in another study. Less extensive procedures may receive single dose prophylaxis, whereas

extensive procedures and those that involve grafts should receive, in our view, antibiotics up to 7 days postoperatively.

Other factors, such as overheating of the surgical site during preparation of the surgical socket, should be avoided. This point merits special attention in the atrophic mandible, where highly dense, poorly vascularized cortical bone is usually the rule. The simultaneous use of bone grafts or biomaterials and removal of the inferior alveolar neurovascular bundle from the mandibular canal are also cited as predisposing causes of infection [65, 66]. Friberg et al. [67] observed postoperative infections accompanied by intense pain after transposition of the inferior alveolar nerve, resulting in the need for removal of implants.

Camps-Font et al. (2015) [68] reported 22 postoperative infections after implant surgery (6.5% of patients and 1.7% of implants). The incidence of infection is variable in the literature due to differences in study design, size of sample, population, among others. Esposito et al. [69] observed that 5.9% of implant patients had postoperative infections. Treatment involves debridement with or without primary closure, local and systemic antibiotics, removal of granulation tissue, removal of exposed grafts and biomaterials and abscess drainage. However, infected implants and grafts are difficult to treat and may require removal [33, 70, 71].

Not all infections will be treated surgically, but success rates obtained with antibiotics alone is considered to be low. Up to 77.3% will require surgical intervention. Early detection and treatment of the infectious process can increase success rate up to 80%. Correct use of mouthwash antiseptics, ambulatory cleansing and irrigation, debridement of the surgical wound, can resolve the infection and preserve implant survival [69]. Infected grafts and biomaterials usually require removal [72]. Table 5 lists measures for prevention of infection after implant surgery.

Table 5 Prevention of postoperative infection

Preoperative systemic
• Nutritional status.
• Control of inflammatory and metabolic disease.
• Cessation of smoking.
• Control of systemic infectious processes.
• Pre-incision antibiotic prophylaxis.
Preoperative local
• Treatment of local infectious and inflammatory processes.
• Pre-incision skin and mucosal preparation.
Transoperative
• Maintain asepsis chain.
• Correct incision type and position for adequate exposure.
• Atraumatic surgical technique.
• Avoid contamination of grafts, biomaterials, and implants prior to insertion.
• Hemostasis and wound irrigation.
Postoperative
• Information of postoperative care to patient.
• Postoperative antibiotics when indicated.
• Antiseptic mouthwash.
• Proper wound care.
• Relative repose in initial postoperative period.

3 Bone-Related Complications

3.1 Osseointegration Failure

Although long-term success rates for dental implants are described as approximately 95% [73], clinical failures still occur [74]. When osseointegration does not occur in weeks or months, implant failure is classified as early. When the implant osseointegrates and later on becomes loose, this is considered to be a late failure. Etiology may be classified as biological or biomechanical [75].

Overheating, contamination and excessive surgical trauma, deficient bone quantity or quality, lack of primary stability, and incorrect indication for immediate loading are some of the causes of immediate failure. Peri-implantitis, occlusal trauma, and overloading are usually related to late failures [13]. Raikar et al. [14] observed that, as the patients age, failure rates presented a tendency to increase, mainly due to changes in bone quality.

In severely atrophic bone, shorter implants, with a greater diameter, became more popular and their survival rates more controversial. Some studies observed increased failure rates for short implants [15, 76]. Others did not find significant influence of implant length on the survival rates [38, 77]. Ivanoff et al. [78] suggested that failure rates of 5 mm-diameter implants increase due to the need for a learning curve to use them, low bone density, implant design, and their use to overcome the lack of primary stability of a conventional implant. Hultin-Mordenfeld et al. [79] concluded the same, analyzing larger diameter implants placed in areas of lower bone density and volume.

Implant failures are always associated to bone loss. They may be detected at the time of implant exposure for prosthetic rehabilitation, representing a true osseointegration failure (Figs. 4 and 5). On the other hand, implants that are incorrectly placed, poorly positioned, or presenting clinical signs of infection, may progress to late failure after the patient is rehabilitated. The early the implant loss occurs, the lesser the bone loss will be. Treatment is implant removal, mechanical debridement, antibiotic therapy, and guided bone regeneration when indicated [33, 80]. Preventive measures for osseointegration failure are shown in Table 6.

3.2 Graft Resorption and Loss

Reconstructive techniques frequently use bone grafts and biomaterials to gain enough bone volume for implant placement. As described above, Bradley [81] observed in angiograms that the subperiosteal plexus may be the main vascular supply to the atrophic mandible. Excessive elevation and releasing of the periosteum may significantly compromise blood supply to the bone in the severely atrophic mandible. Stability of the graft is important both for initial integration, as well as to maintain graft bulk long term. Lack of stability predisposes to resorption and even infection, leading to excessive resorption, loss of graft volume, and the need to eliminate infected material.

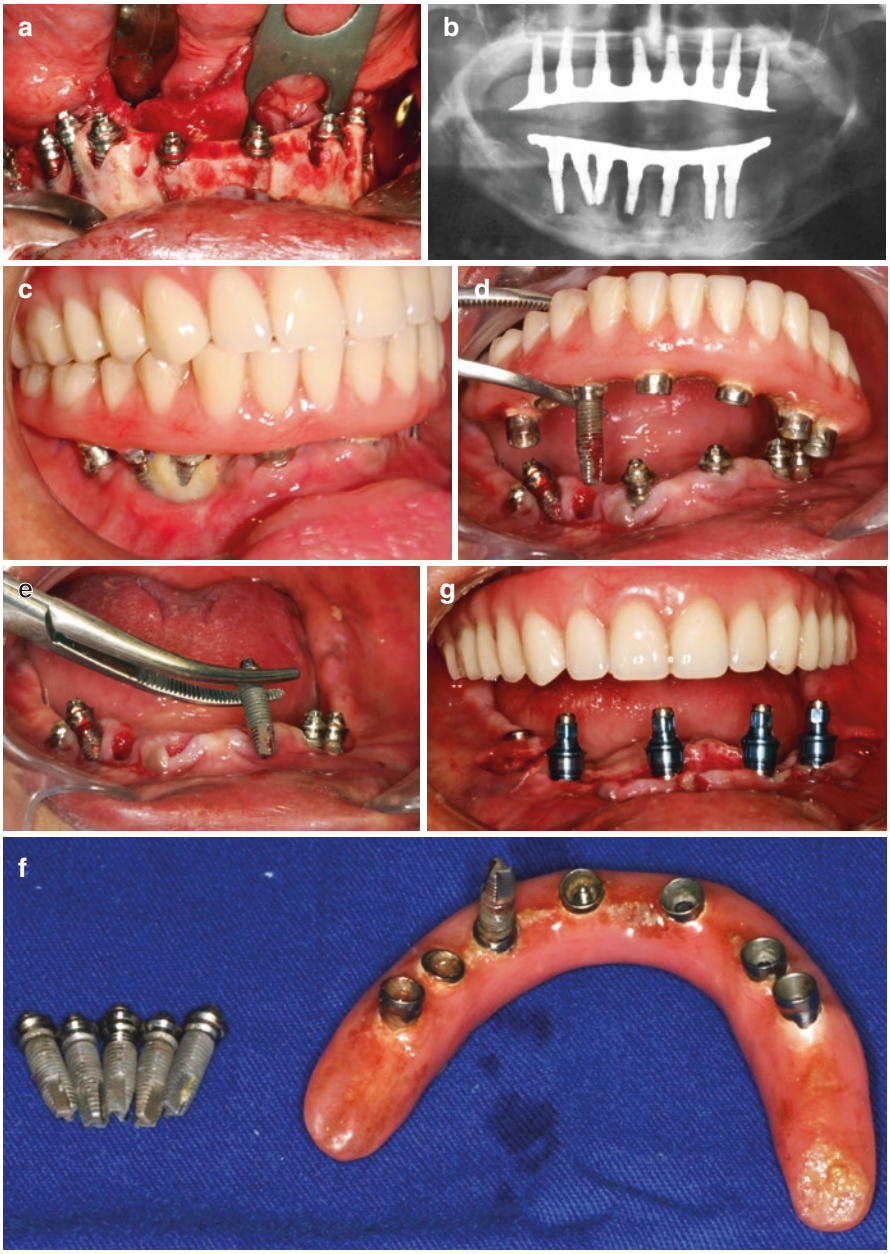

Fig. 4 (**a**) Implant installation without alveoloplasty in the posterior regions. (**b**) Panoramic radiograph showing bone loss around implants. (**c**) Devitalized exposed bone. (**d**) Loose implants. (**e**) Removal of implants. Absence of osseointegration. (**f**) Prosthesis and implants removed. (**g**) Alveoloplasty and new implants. (**h**) Panoramic radiograph after 5 months, postoperatively. (**i**) Final prosthesis. (Courtesy of Dr Leandro Benetti, Brazil)

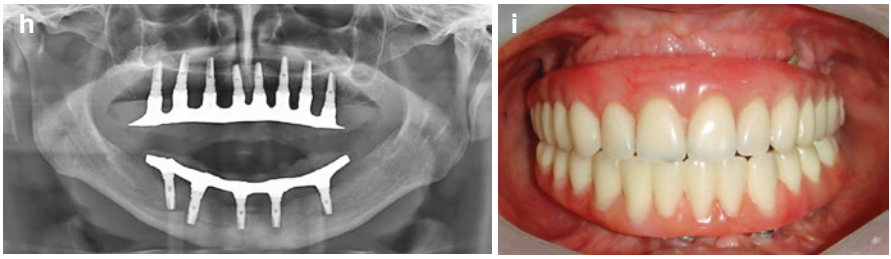

Fig. 4 (continued)

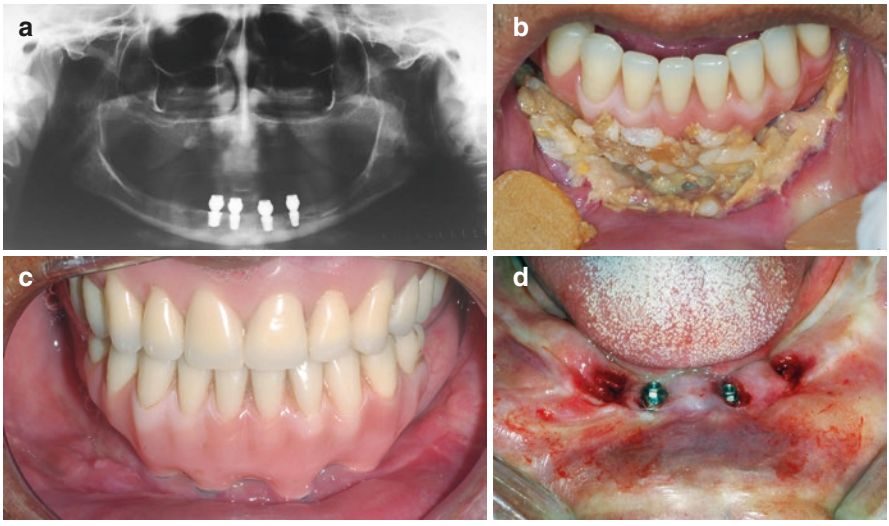

Fig. 5 (**a**) Short implants placed on the anterior mandible. (**b**) Dehiscence and extremely poor oral hygiene. (**c**) Prosthesis after local treatment of dehiscence. (**d**) Loss of two implants

Table 6 Prevention of osseointegration failure

Preoperative identification of disease or medications affecting bone metabolism
Precise evaluation of bone quality and quantity
Avoid overheating of bone
Proper aseptic and atraumatic surgical technique
Correct selection of type and size of implant
Alveoloplasty before implant insertion when indicated
Correct implant positioning
Obtain primary stability
Correct indication of immediate loading
Proper planning of prosthetic rehabilitation avoiding overloading
Balanced occlusion
Thorough periodontal care and periodical revision

Bone volume obtained during surgery undergoes a progressive decrease in volume, which tends to be greater for autogenous bone than for bone substitutes and also greater for vertical than for horizontal augmentations [82] (Fig. 6). Resorption is usually greater before implant placement and significantly decreases after that. According to the literature, areas augmented by bone blocks taken from the mandibular ramus present resorption rates of 5–28% [83, 84].

Dislodging of grafts and biomaterials can also compromise bone gain in the sites where it is necessary. Sterio et al. [85] observed resorption or dislocation of 50% of the grafted material used in horizontal reconstructions after 6 months. This can result in late exposure of the grafts or implanted biomaterials, creating the need for reintervention and partial or complete removal of the reconstructive material. While bone blocs will be usually fixed by screws, granular biomaterials or particulate bone are dependent of the integrity of the soft tissues and the use of membranes for stability and diminished ingrowth of fibrous tissue [85]. Incomplete revascularization of block grafts may also result in early or late exposure of the graft and implant loss (Fig. 7)

In any case, integrity of the soft tissues is fundamental for successful alveolar ridge augmentation. Lacerations or perforations of the mucosa predispose to exposure, infection, and possible partial or complete loss of the graft or biomaterial used in the reconstruction. Reintervention in bone-grafted areas predisposes to excessive resorption. Block grafts should have all the sharp corners rounded to protect the overlying mucosa. Careful planning of the osseous reconstruction is important before implant placement. The use of block or particulate bone substitutes associated to membranes is only possible where there is enough remaining host bone to promote osteogenesis [86]. Table 7 refers to preventive measures for graft resorption and loss.

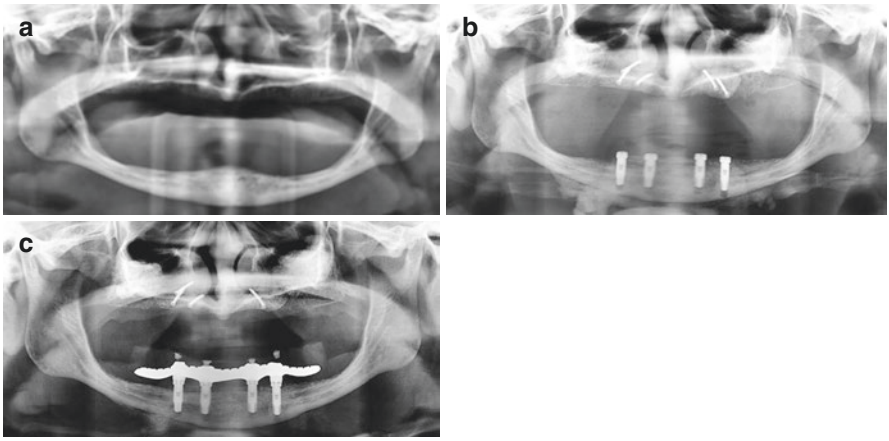

Fig. 6 (**a**) Preoperative radiograph. (**b**) Implants placed with the tent-pole technique with autogenous particulate anterior iliac crest bone graft and biomaterial. (**c**) Partial vertical resorption of the graft

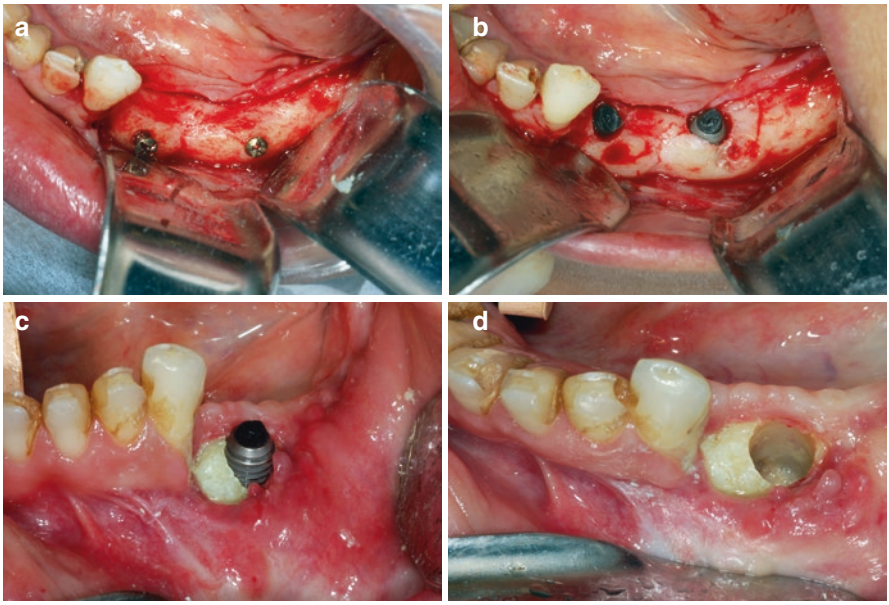

Fig. 7 (**a**) Reopening of autogenous ramus block graft. (**b**) Implants placed. (**c**) Exposure of graft and implant. (**d**) Loss of implant

Table 7 Prevention graft resorption

Preoperative identification of disease or medications affecting bone metabolism
Choose the correct reconstructive materials
Avoid perforation or laceration of the soft tissue
Preservation of integrity of the periosteum
Stability of grafts/biomaterials
Eliminate sharp edges of block grafts
Correct use of membranes

3.3 Fractures of the Mandible

Luhr et al. [52] classified mandibular atrophy based on the height of the mandibular body, because this is the area more prone to fracture. They aimed to assess the difficulty to treat atrophic mandible fractures and thus included only mandibles with a height of 20 mm or less. Those with a height of 16–20 mm were named class I; those with 11–15 mm were class II and if 10 mm or less in height were considered to be class III.

Severe atrophy of the mandible reduces its surface area, bone density and vascularization, increasing the risk of treatment failures and mandibular fractures. Severely atrophic mandibles constitute a challenging condition in implantology, due to the minimal amount of remaining bone support, especially vertically, low bone quality and vulnerability to fractures [8, 9, 87, 88].

The remaining cortical bone is brittle and this also predisposes to fractures. Mandible fractures may occur during implant or reconstructive surgery, as well as postoperatively. Due to the weakness of the atrophic mandible, fractures may happen during the preparation of the surgical socket by rotary instruments or as a function of the type of bone reconstruction used. They may also follow the loss of implants (Fig. 8). Muscle pull tends to dislocate the fracture, producing a very difficult clinical problem [89, 90].

Although implant surgical complications in the mandible, such as pain, swelling, postoperative bleeding, and nerve damage are more frequent [89], the fracture of the atrophic mandible is one of the most serious complications associated to its reconstruction and rehabilitation [90]. Bone augmentation procedures can be used to prevent early or late fractures. The application of the tent-pole technique or particulate grafts under customized titanium meshes are good options to gain bone stock in the anterior mandible [91].

Several factors are associated to mandibular fractures in this setting. Preparation of the implant socket fragilizes the remaining bone and installation of the implants generates forces and enough mechanical stress on the poor-quality bone, sufficient to create microfractures. Thus, excessive torque should be avoided. Soehardi et al. [92] evaluated the occurrence of fractures during implant installation from 1980 to 2007. They found that 52% of the surgeons had 157 mandible fractures associated with implant placement in edentulous mandibles. An incidence of less than 0.05% was estimated, based on a population of approximately 475,000 patients treated with at least two implants to support an overdenture. Fractures were more frequent in mandibles presenting 5–10 mm of height and all happened in the area of implant socket preparation.

Less atrophic mandibles can also be fragilized by loss of implants during surgery or postoperatively and be susceptible to fractures. Lateralization of the inferior alveolar nerve for implant placement, intraoral removal of bone blocks for grafting and alveolar distraction may result in mandible fractures (Fig. 9). Kan et al. [93] observed a spontaneous fracture of the mandible after nerve lateralization, which was attributed to the vestibular bone window created to access the neurovascular bundle. Prdjik et al. [94] describe a 20% incidence of fractures in patients submitted to distraction osteogenesis. Risks can be minimized by adequate planning of those procedures [95].

Bicorticalization or transfixation of the inferior border of the mandible by the implant may favor a mandible facture. Placement of shorter implants, maintaining the integrity of the lower border of the mandible, reduces the risk of fracture. Short implants can be considered a good alternative for cases of significantly reduced bone height. The literature has demonstrated that short implants are a simple treatment that carries low morbidity. However, in severely atrophic mandibles the risk of fracture during the placement of short implants is still present, mainly due to socket preparation in extremely cortical atrophic bone [92].

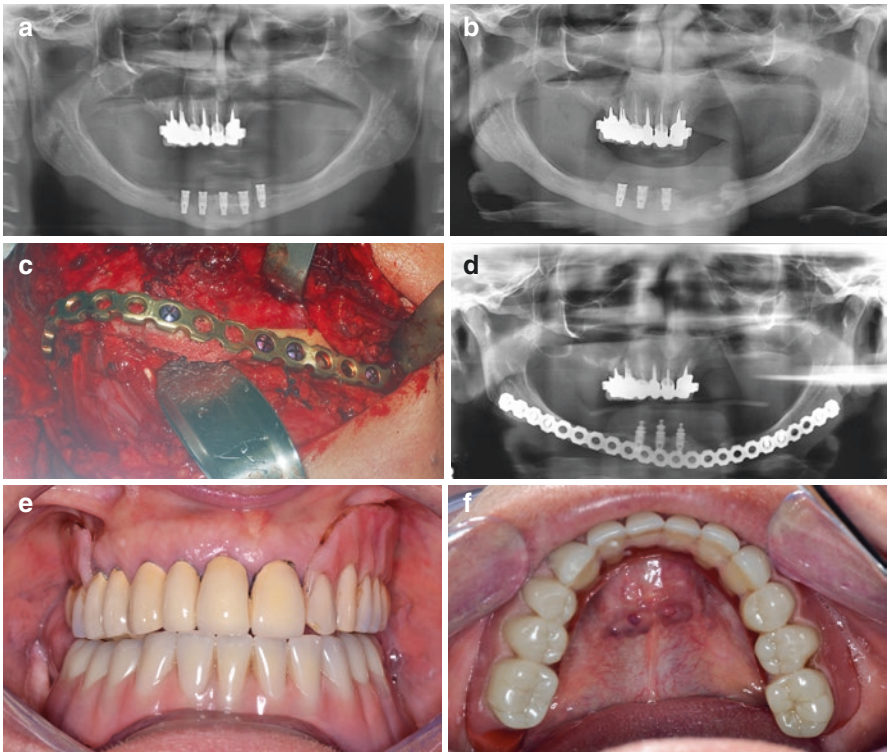

Fig. 8 (**a**) Implants installed by guided surgery. (**b**) Fracture of the mandible after spontaneous loss of two implants. (**c**) Mandibular reconstruction with autogenous anterior iliac crest block bone graft and a locking mandibular reconstruction plate. (**d**) Postoperative radiograph after 6 months. O-ring abutments in place over the remaining implants. (**e**) Patient rehabilitated with an overdenture. (**f**) Inferior prosthesis adaptation

Oh et al. [96] described a case of mandibular fracture 3 months after placement of 2 short implants in the anterior region of a severely atrophic mandible. Mason et al. [97] reported two cases of mandibular fracture after placement of 7 mm implants in elderly women. Reports of fractures after installation of short implants are scarce in the literature and survival rates are described as high [98].

Fractures of the atrophic mandibles pose a significant problem. They usually occur in elderly persons, who may present systemic comorbidities. Atrophic mandibles are considered to represent poor-quality bone for fracture osteosynthesis. The distinction between tension and compression zones, clear in the dentate mandible, is lost in the atrophic mandible. Moreover, the areas suitable for placement of screws in atrophic mandibles are the symphysis and the mandibular angle and ramus area. The poor-quality bone, also lacking in quantity for proper buttressing and the need to bridge the resorbed mandibular body with the osteosynthesis plate, create the need for load-bearing osteosynthesis [99] (Fig. 10).

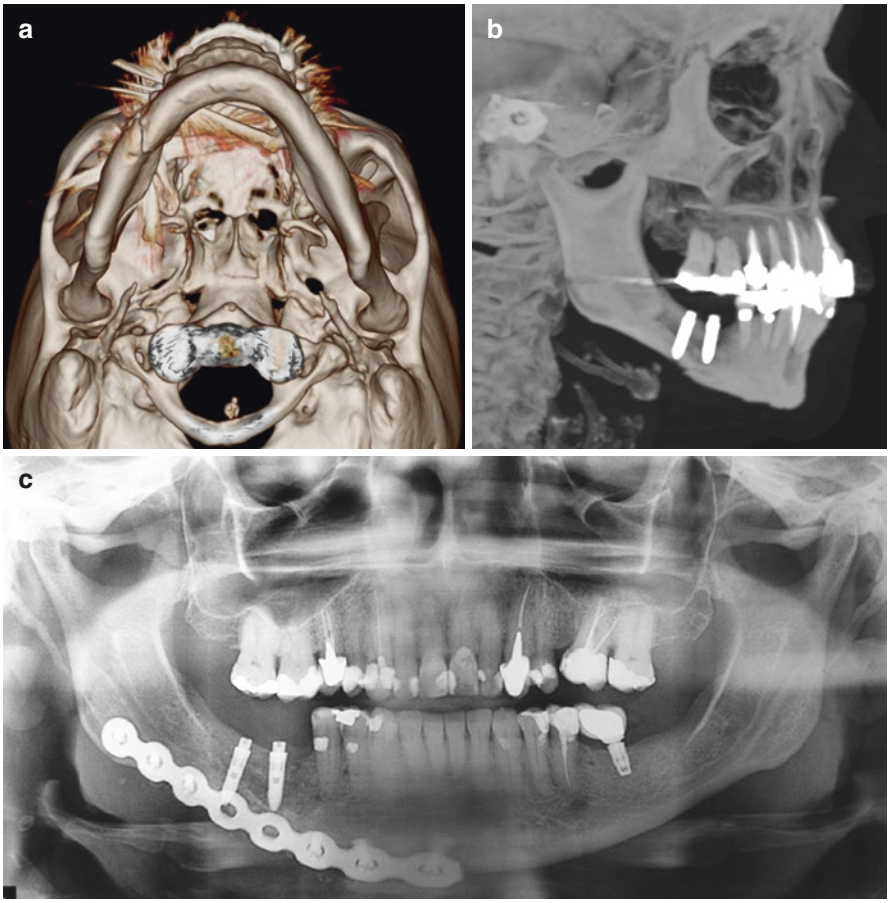

Fig. 9 (**a**) Spontaneous right mandibular body fracture in the early postoperative period after inferior alveolar nerve lateralization. (**b**) Lateral view of the fracture. (**c**) Fracture osteosynthesis that performed by an extraoral approach

According to Ellis and Price [88], the most predictable method of treatment for fractures of the atrophic mandible is open reduction and internal fixation with mandibular reconstruction plates, through extensive extraoral transcutaneous access [52, 100]. There is also the possibility to associate bone grafting to the fracture treatment in order to favor the healing at the fracture line and gain bone volume [81, 87]. The repair of such fractures thus requires significant surgical procedures. Treatment time and cost will be significantly increased, osteosynthesis material will interfere with the areas of implant placement, the type of prosthesis may need to be changed, skin incisions may leave visible scars and there is potential for neurosensory and motor alterations, besides medical-legal implications [101]. Table 8 shows measures related to the prevention of mandible fractures.

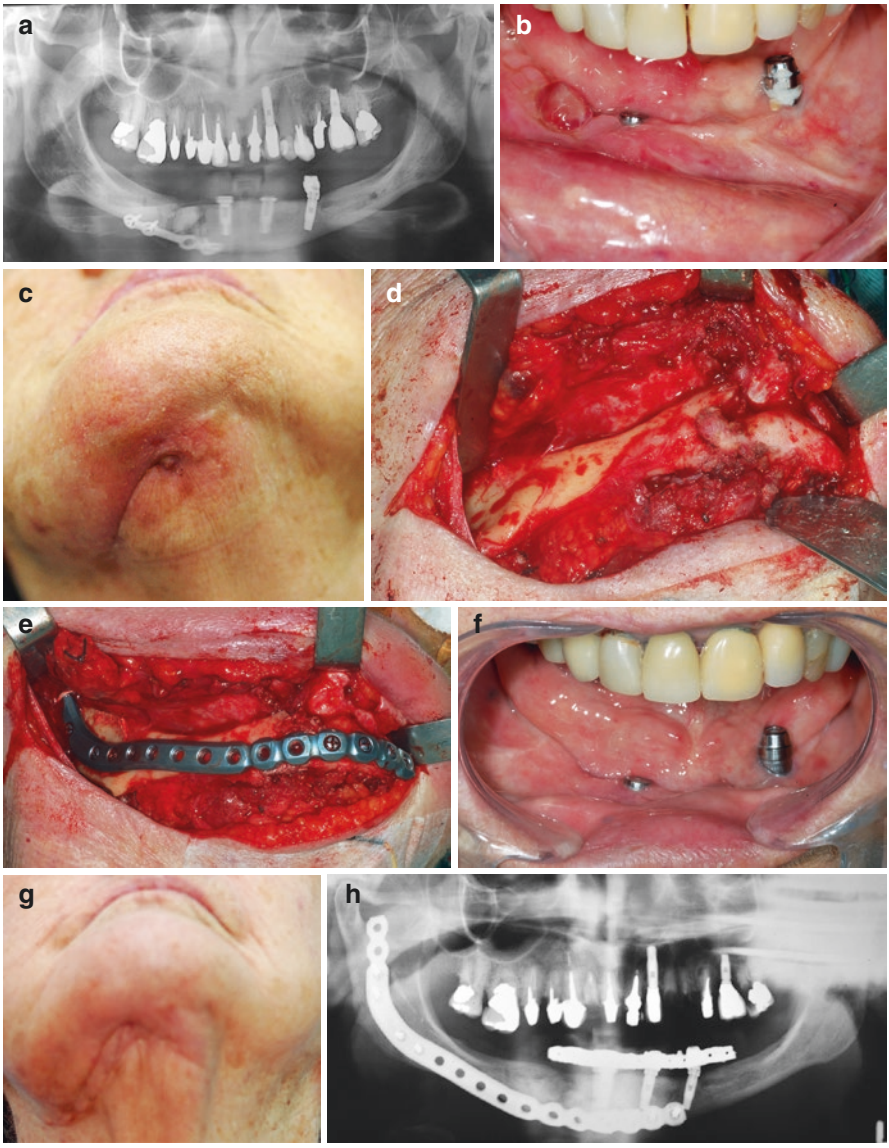

Fig. 10 (**a**) Fracture after implant placement, incorrectly treated with a small plate and insertion of biomaterial into the implant socket. The fracture is mobile and infected. (**b**) Intraoral fistula. (**c**) Extraoral fistula. (**d**) Exposed mandible after removal of the miniplate and biomaterial. (**e**) Mandibular reconstruction with load bearing osteosynthesis and autogenous anterior iliac crest particulate graft. (**f**) Resolution of intraoral fistula in the early postoperative period. (**g**) Resolution of extraoral fistula. (**h**) Panoramic radiograph after consolidation of the fracture

Table 8 Prevention mandibular fractures

Careful planning of implant position
Preparation of implant socket compatible with residual bone volume
Avoid excessive implant torque
Avoid bicorticalization or transfixation of implants through the inferior border
Consider the use of short implants
Consider the need for bone augmentation with grafts
Avoid nerve lateralization when feasible
If lateralization needed, minimize bone window
Precise planning of distraction procedures

3.4 Drug-Induced Osteonecrosis

Among antiresorptive drugs, bisphosphonates are the most prescribed. They participate in the treatment of skeletal and oncological diseases, such as breast, lung and prostate cancer, multiple myeloma, hypercalcemia, osteoporosis, and Paget's disease. According to the IMS Health in 2006, approximately 190 million units of oral intake drugs were used worldwide for the treatment of osteoporosis and osteopenia. Most of the patients treated with bisphosphonates, due to their age, present partial or complete edentulism and are candidates for oral rehabilitation with dental implants or have already received rehabilitation before they initiated treatment with those drugs [102, 103].

Medication-related osteonecrosis of the jaws (MRONJ) is defined as the exposure of bone for more than 8 weeks in the oral and maxillofacial region, in patients who are under treatment with antiresorptive medication, without any radiation treatment or previous oral surgical intervention [104]. However, intraoral procedures may initiate or complicate the process [59]. There is no well-defined relation between bisphosphonates and osseointegration of dental implants. Bisphosphonates increase mechanical stability of dental implants when applied locally but increase the risk of osteonecrosis of the mandible when used systemically. This drug class can drastically reduce bone blood perfusion and interfere in the bone and vascular turnover, affecting the quality of the osseous tissue. Those medications have a cumulative effect and alter the homeostasis of the newly formed bone around dental implants, creating an infection-prone environment [93].

According to the guidelines of the American Association of Oral and Maxillofacial Surgeons, implant surgery is contraindicated in patients treated with intravenous (IV) bisphosphonates. However, a significant new problem encountered in the literature is those patients who were already rehabilitated with dental implants and initiate tumor treatment with bisphosphonates, due to late onset osteonecrosis [104] (Fig. 11).

In regard to the oral antiresorptive drugs, there are several questions to be considered. Basal pathology, administration route, length of use, frequency of use, type of medication, dosage, and type of procedure are important for treatment decisions [105, 106]. A systematic review with metanalysis, including 6 retrospective and

2 prospective studies, considering 1288 patients and 4564 implants was published in 2014. Results showed that success rates for implants placed in patients taking oral bisphosphonates were not reduced and there was not sufficient evidence of negative impact on dental implants [107]. A more recent study showed that 59% of patients who developed osteonecrosis of the jaws after dental implants had received therapy with intravenous bisphosphonates, but the remaining 41% were taking oral bisphosphonates [108]. Thus, although the probability of osteonecrosis after implant surgery in patients using oral drugs is lower, it is still present (Fig. 12).

Serum carboxiterminal telopeptide of type I collagen (CTx), a marker of bone resorption, is used as a risk predictor for osteonecrosis in patients taking antiresorptive drugs. The risk of osteonecrosis for a given patient is classified accordingly to the serum level of CTx as low (>150 pg/mL), moderate (between 100 and 150 pg/mL), and high (<100 pg/mL). Levels are thought to increase approximately 26 pg/mL per month if the medication is removed. However, while a moderate or high risk result discloses risk for osteonecrosis, a low risk result does not exclude the possibility of osteonecrosis [109].

Moreover, bisphosphonates are not metabolized and are either excreted by the kidneys or deposited in the bones. Bone deposition is cumulative with usage and the drug can remain in the organism for decades, without no known method of removal from the bones. The duration of the physiologic effect is unknown, but it certainly persists for years. For that reason, short-term interruption of the medication has poor effect in the prevention of osteonecrosis [110, 111].

In patients who will begin the use of bisphosphonates, all jaw pathology should be treated and elective surgery performed at least 3 months before initiating the medication, when feasible. In patients for whom intravenous bisphosphonates are mandatory, dental implants should be contraindicated [107].

Osteonecrosis related to the use of antiresorptive drugs may be localized or widespread in the mandible, but it is very difficult to treat, because it is frequently progressive, even with proper treatment. For patients diagnosed with MRONJ the objective is to prevent disease progression, remove bone sequesters, resolve infection, and recover mucosal lining. The treatment involves the use of oral rinses; chlorhexidine or oxygen releasing gel; hyperbaric oxygen therapy; long-term use of oral vitamin E, pentoxifylline and antibiotics; surgical debridement or resection. In many cases, treatment also involves removal of teeth and implants [112]. Doh et al. reported a case of MRONJ after dental implant placement. Management included stimulation of osteoblasts with recombinant parathyroid hormone and conservative treatment, resulting in complete mucosal repair [113].

Nonexistence of consensus about treatment, lack of knowledge about the physiopathology of the disease and negligence about anticipated oral care of patients who will be taking antiresorptive drugs, render drug-induced osteonecrosis a significant public health problem to be addressed in the short-term future, in view of the increase in the use of bisphosphonates to treat osteoporosis and oncologic disease, coupled with the increase in the number of implant supported rehabilitations [114]. Table 9 lists preventive measures of drug-induced osteonecrosis.

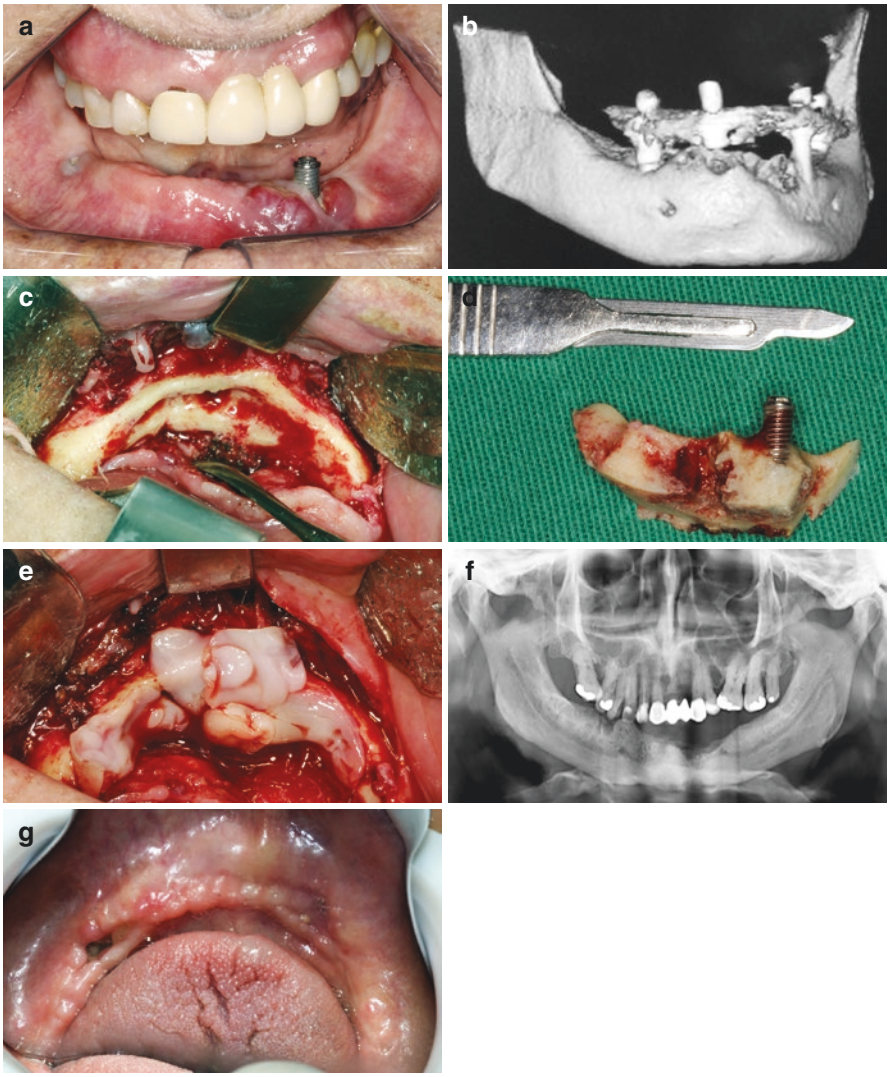

Fig. 11 (**a**) Patient who was started in intravenous bisphosphonates for cancer treatment 2 years after oral rehabilitation with dental implants. He was evaluated after spontaneous loss of two implants, with pain and local infection. (**b**) Cone-beam CT scan compatible with osteonecrosis. (**c**) Removal of necrotic bone and implants. (**d**) Removed bone segment. (**e**) Covering of viable bone with leucocyte platelet-rich fibrin. (**f**) Postoperative radiograph after 45 days. (**g**) Healing of mucosa after 45 days

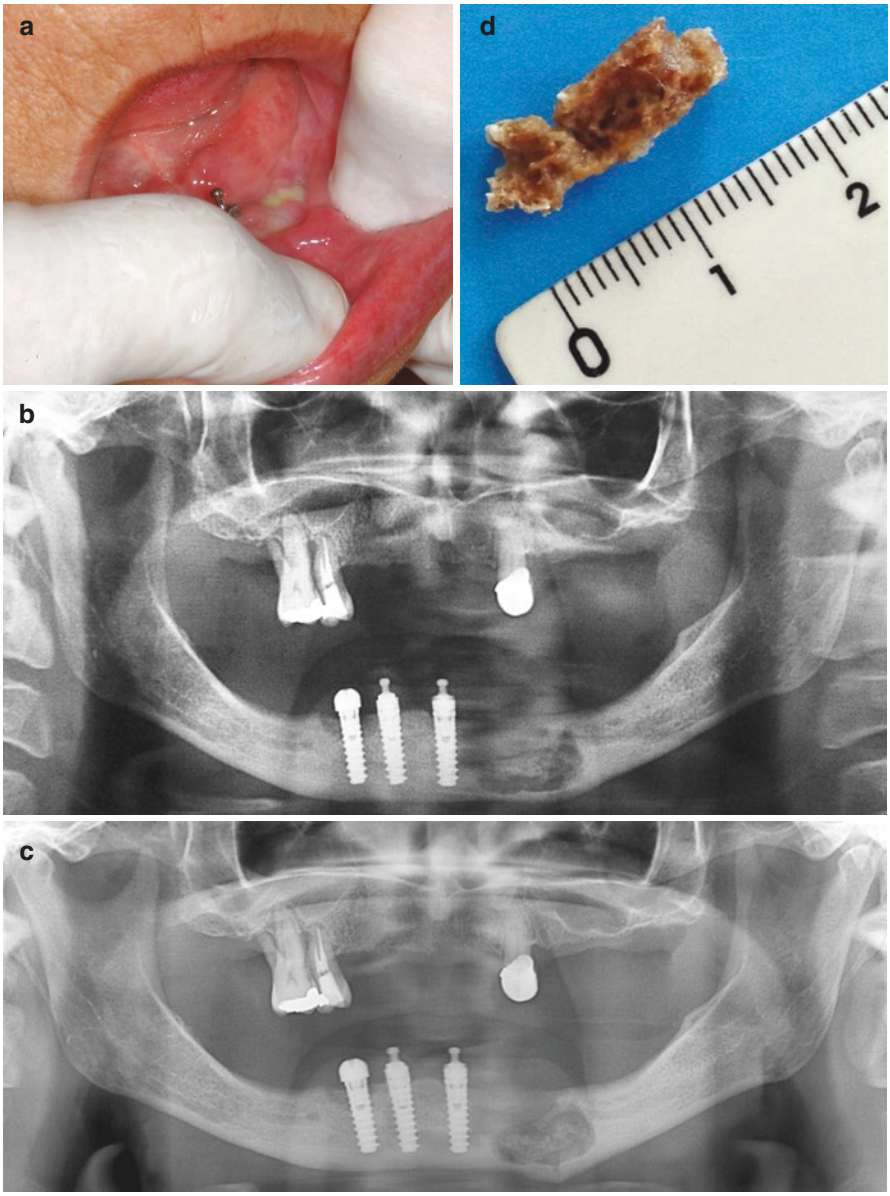

Fig. 12 (**a**) Infection with intraoral drainage after loss of implant in patient using oral bisphosphonates for treatment of osteoporosis. (**b**) Area of osteonecrosis in anterior mandible. Local and systemic conservative treatment was instituted. (**c**) Bone remodeling adjacent to implant. Bone sequester still present in the mandible. (**d**) Extruded bone sequester. (**e**) Radiograph after resolution of infection

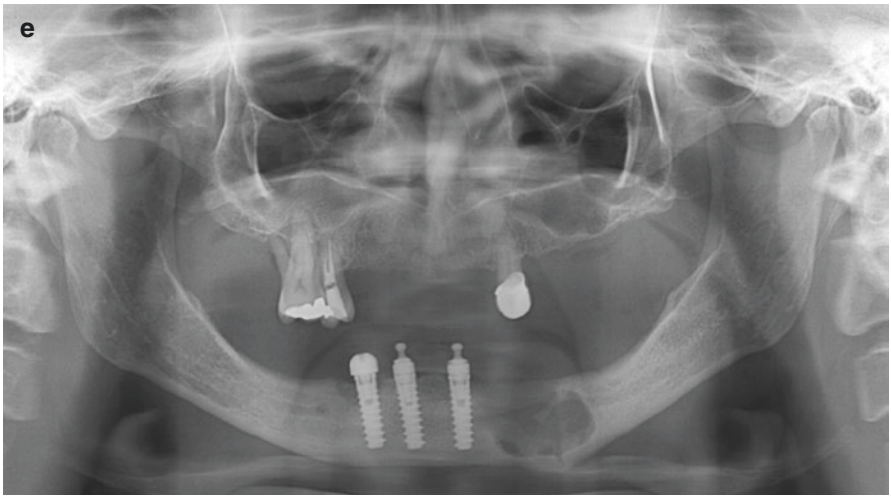

Fig. 12 (continued)

Table 9 Prevention of drug-related osteonecrosis

Correct information about the drugs in use by patient
Use CTx results with care
Thorough maintenance of oral hygiene
Perform invasive dental treatment and elective surgery 3 months before initiating antiresorptive drugs
Avoid surgery in patients treated with IV bisphosphonates
Follow closely patients who initiated antiresorptive drugs after implant rehabilitation

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Trigeminal Nerve Injuries

Elise L. Ehland, Roger A. Meyer, and Shahrokh C. Bagheri

Injuries to peripheral branches of the mandibular division (V3) of the trigeminal nerve (TN5) should be of concern to dentists who place dental implant fixtures into the mandible. The TN5 supplies sensation to the face, mouth, teeth, and jaws (Fig. 1) These anatomical locations are involved in many important activities of daily living which depend on intact sensory input (Table 1). An injury to a branch of V3 (i.e., inferior alveolar nerve, IAN; mental nerve, MN; lingual nerve, LN; long buccal nerve, LBN) during dental implant surgery is a known and accepted risk of such procedures.

Despite knowledge of the anatomy, thorough preoperative evaluation, and proper surgical technique, TN5 injuries cannot always be avoided. Unfortunately, such injuries can cause loss or alteration of sensory perception (*paresthesia)* and/or painful sensation (*dysesthesia*). Patients may experience interference with orofacial activities on a spectrum from mild discomfort or annoyance to severe prostrating or debilitating pain and/or hypersensitivity. The resulting symptoms and/or functional impairments are distressing to patients, especially if the symptoms do not resolve

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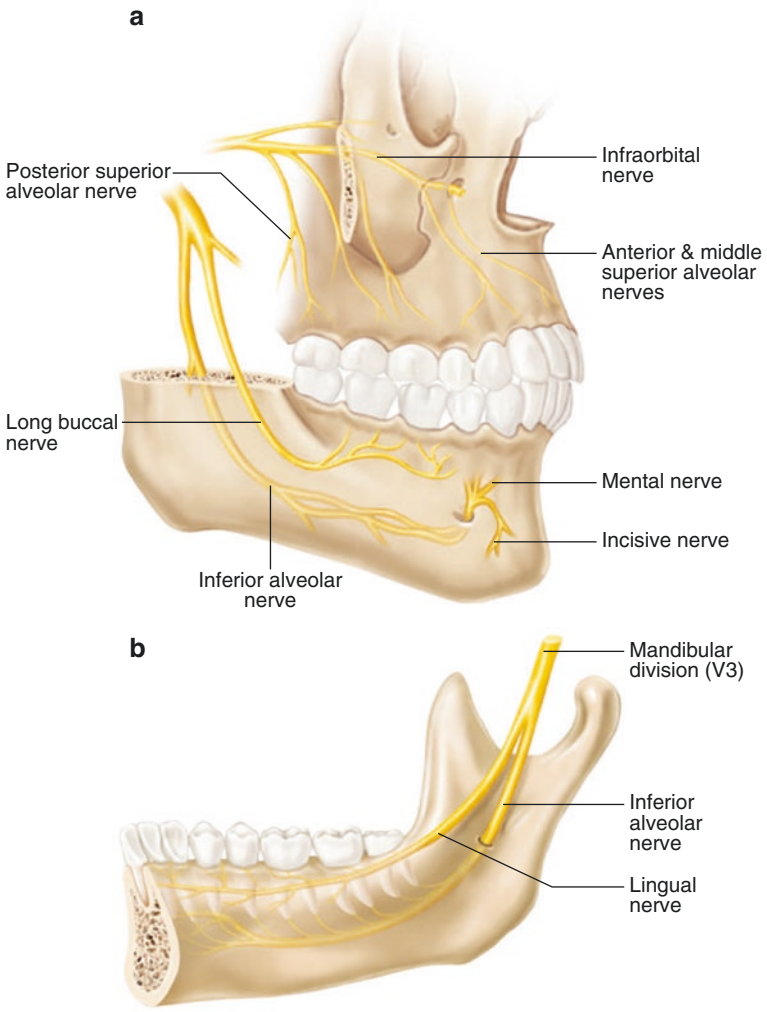


Fig. 1 (**a**) lateral aspect of maxilla and mandible; (**b**) medial aspect of mandible. Miloro M (ed): Trigeminal Nerve Injuries, Springer, 2013, Fig. 3.2, p. 29

Table 1 Important orofacial activities of daily living which can be adversely affected by an injury to a peripheral branch of the trigeminal nerve

Chewing food	Speaking/singing
Drinking liquids	Kissing and other oral sexual activity
Tooth brushing and flossing	Playing wind musical instruments
Face washing	Applying lipstick/make-up
Shaving	Smoking

promptly and the patient was not informed of the risk before treatment. Nerve injuries are currently the second leading cause of litigation against dentists in the USA. The "informed consent" doctrine in most states requires that the patient be informed of the risk of nerve injury during the preoperative discussion of dental

implants and the signing of a consent form. These injuries do not always heal, nor do the unpleasant sensations resolve, spontaneously. Such sequelae, if allowed to persist, can have devastating effects on a patient's quality of life. Therefore, prevention or early treatment of nerve injuries is essential in the care of the dental implant patient [1, 2].

1 Etiology and Prevention

Preoperative evaluation is integral to the successful completion of a dental implant procedure. Inadequate imaging of the mandible to determine the exact location of the inferior alveolar canal (IAC) and the mental foramen (MeF) is a common source of error leading to improper placement of an implant, especially when the mandibular alveolar ridge has become atrophic (Fig. 2). In such cases, the vertical distance from the crest of the alveolar ridge to the superior wall of the IAC may be inadequate for the length of the implant. Knowing this in advance enables the clinician to alter the treatment plan by either choosing an implant of lesser length or doing a nerve-repositioning procedure. A panoramic film, calibrated to reduce distortion, is the minimum requirement. In situations where the IAN or the MN is at risk of encroachment by the drilling procedure or implant placement, a three-dimensional imaging study (i.e., computed tomographic scan, CT; or, cone-beam computed tomographic scan, CBCT) provides additional important information (Fig. 3).

Every step of the implant procedure poses a risk of injury to the IAN, MN, LN, and LBN during the placement of dental implants into the mandible [1]. The well-trained, experienced, and proactive clinician will be able to modify his or her technique according to the needs of each patient to minimize the risk of nerve injury. Below are discussed those situations where nerve injuries may occur during dental implant procedures.

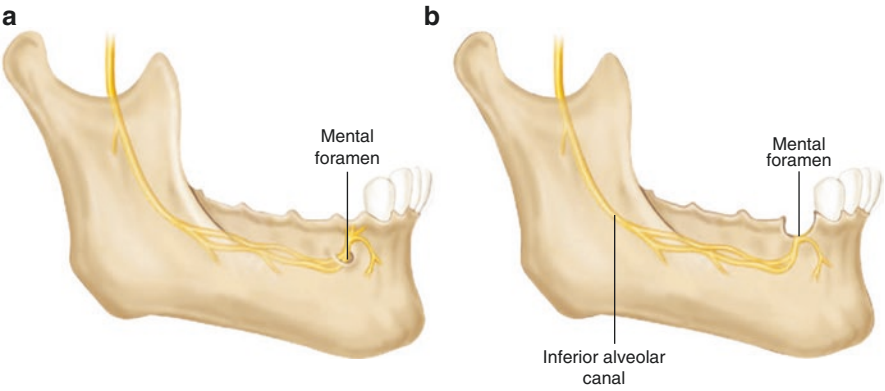


Fig. 2 (**a**) Superior position of the mental foramen due to resorption of alveolar bone in the area; (**b**) Inferior alveolar nerve in proximity to alveolar ridge. Miloro M: Trigeminal Nerve Injuries, Fig. 6.5 (**a**, **b** only), p. 93

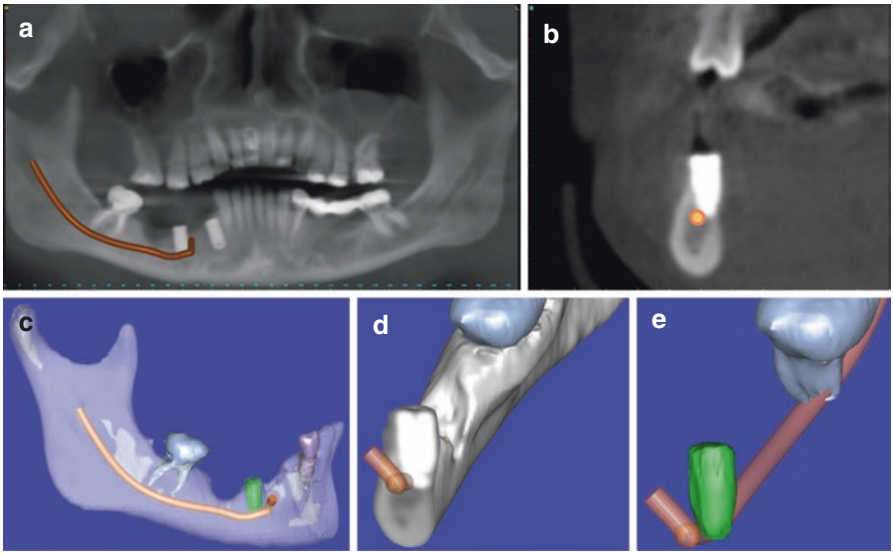


Fig. 3 (**a**) CBCT generated panoramic radiograph with right inferior alveolar canal in proximity to #29 dental implant; (**b**) Coronal slice of the same patient demonstrating #29 dental implant impingement on the right inferior alveolar canal; (**c**) 3D reconstruction with transparency of the osseous structures; (**d**) Cross-section of 3D reconstruction; (**e**) Osseous structures removed from previous image. Miloro M: Trigeminal Nerve Injuries, Fig. 6.6, p. 95

1.1 Errors in Diagnosis and Treatment Planning

Identification of the position of the inferior alveolar canal (IAC) can be determined with radiographic evaluation. The IAC defines the boundaries of the inferior alveolar neurovascular bundle. Anatomical analysis demonstrates that the IAN occupies approximately 80% of the canal space, the other 20% occupied by the inferior alveolar artery and vein. There is great variation in the position of the artery and vein in relation to the nerve. The panoramic radiograph (orthopantomogram) is useful as a primary imaging study to evaluate the vertical distance from the crest of the alveolar bone to the position of the IAC. Each panoramic system should be calibrated with its software to account for distortion and magnification. There is generally a magnification of 10–40% with more magnification of areas that are outside the focal trough of the beam. A typical magnification of the mandible is 20%. As a two-dimensional image, the mediolateral position of the IAC and path of the mental nerve anterior loop cannot be accurately assessed.

If there are anatomical concerns or if virtual surgical planning is indicated or desired, a computed tomographic (CT) scan or cone-beam CT scan is necessary. There have been many advances with implant planning software which is available to develop CT-guided implant planning and custom surgical guides. Regardless of the radiographic modality used, errors in interpretation and application may lead to errors in implant positioning. Errors in digital implant planning may also be transferred to the surgical procedure. With regard to the surgical guide, attention should be given to the accuracy and stability of the guide in situ. Surgical guides supported

by an edentulous mandible will have a margin of error related to the soft tissue despite correct digital planning. The use of a "flapless" technique for implant placement has gained popularity for a variety of reasons, it is accepted as less accurate than direct visualization of the alveolar bone. The surgeon should never hesitate to reflect a mucoperiosteal flap for better visualization and accuracy. Bone-borne and tooth-borne guides may help to improve accuracy and stability of a surgical guide by providing a fixed landmark. When planning implant length and depth of placement, it is important to allow an additional distance (2 mm) from the superior aspect of the IAC to allow for any margin of error in planning or placement.

1.2 Local Anesthesia

Injection of local anesthetic might cause nerve injury by direct trauma to nerve tissue or adjacent blood vessels or chemical toxicity to the nerve [3]. Introduction of a local anesthetic needle into the pterygomandibular space (PTMS) in close proximity to the IAN and LN is essentially a blind procedure. It is a testament to the clinician's careful technique that such a small percentage of injections result in significant nerve injury. In order to minimize this risk, the authors recommend a protocol for local anesthetic injections [4]. In the fully conscious patient, the local anesthetic needle is inserted into the proper location in the PTMS. If the patient does not complain of sudden sharp pain or shocking sensation (*dysesthesia)* which may radiate to the lower teeth, lower lip, lower jaw, or tongue, the syringe is aspirated. If the aspirate contains no blood, the local anesthetic solution is injected with the needle position unchanged. However, if there is a bloody aspirate, the needle is withdrawn 2–3 mm and aspiration is repeated. If the aspirate is now clear, the local anesthetic solution is injected with the needle in the new position. If the patient experiences dysesthesia, the clinician proceeds similarly as with a bloody aspirate. After withdrawal of the needle (as above), the injection proceeds. If there is a bloody aspirate or a dysesthesia during the injection, the incident is noted in the patient's record, and an evaluation of sensory function is done at the patient's next visit. When the patient is under intravenous sedation or general anesthesia, he/she will not be able to react to a dysesthesia. Therefore, aspirate before the injection and proceed as described above.

1.3 Surgical Flap

During the incision, elevation, or retraction of mucoperiosteal flaps, attention to the position of the IAN, MN, LN, or LBN is especially important when the mandible has undergone significant alveolar resorption. The mental nerve branches are within the buccal and labial mandibular soft tissues and at risk of iatrogenic injury during a vestibular incision. They are also at risk of thermal injury from use of electrocautery in close proximity. Recognition of the anatomical position of the mental foramen, the intra-bony mental loop and the approximate position of the branches within the soft tissues is particularly important in preventing injury to this portion

of the nerve. It is also important to recognize the changing anatomy of the edentulous mandible. As mandibular alveolar bone resorbs with age, the position of the mental foramen approaches the crest of the alveolar ridge. In some patients, there is an actual dehiscence of the IAC and the IAN and MN come to lie on the crest of the alveolar ridge (Fig. 2). Therefore, incision design must take this anatomical position into consideration.

Injury to the MN and its branches may also be sustained as a stretch or retraction injury. During the elevation and retraction of a mucoperiosteal flap, which may also contain a nerve, gentle manipulation and retraction with frequent brief periods of relaxation of retraction pressure is indicated.

1.4 Nerve-Repositioning

A nerve-repositioning procedure is sometimes helpful to relocate the IAN or MN out of harm's way when preoperative imaging studies indicate that the nerve would be in the path of a properly positioned implant [5]. These procedures demand precise and careful microsurgical technique and should only be undertaken by a surgeon with training in microneurosurgery. The procedure can be done at the same operation as the placement of the dental implant (Fig. 4). An autogenous bone graft, either from the bone removed to unroof the IAC or elsewhere (e.g., from the ipsilateral mandibular ramus) is placed between the repositioned nerve and the associated implant(s) to prevent direct contact and thermal transmission between the implant(s) and the nerve. Alloplastic material, such as calcium hydroxyapatite, should never be placed in direct contact with a nerve. A severe inflammatory reaction producing dense scarring of the nerve, accompanied by intractable pain, is often the unfortunate result. Surgical or other treatment of such injuries is problematic [1]. Exposure and retraction of the nerve, although not causing anatomical disruption, is always followed by one to several months of decreased sensation [6]. Careful exposure, retraction, and repositioning of the nerve will reduce, but not entirely eliminate the risk of permanent nerve dysfunction. However, in most patients the sensory function returns ultimately to normal or acceptable (to the patient) status.

1.5 Implant Osteotomy

An osteotomy in preparation for implant insertion can cause injury to the IAN. Errors in planning due to inaccurate measurements from distorted imaging studies and miscalculation of drill depth allow penetration of the inferior alveolar canal (IAC) and direct trauma to the IAN (Fig. 5). Indirect nerve trauma can occur, if inadequate cooling of the drill allows generation of excessive heat, thereby causing a thermal nerve injury. Taking preoperative measurements from calibrated imaging studies, careful drilling technique with frequent intraoperative verification of drill dimensions (diameter and length), and irrigation with adequate coolant minimize such risks to adjacent nerves.

1.6 Implant Placement

Over-insertion of the implant with either indirect contact by dislodged bone impacting on the IAC or entrance into the IAC with direct nerve contact cause compression injury of the IAN. Disruption of the superior wall of the IAC during the drilling procedure or by over-insertion of the implant may cause a ***delayed nerve injury.*** As osseous regeneration occurs, production of new bone may be greater than that which

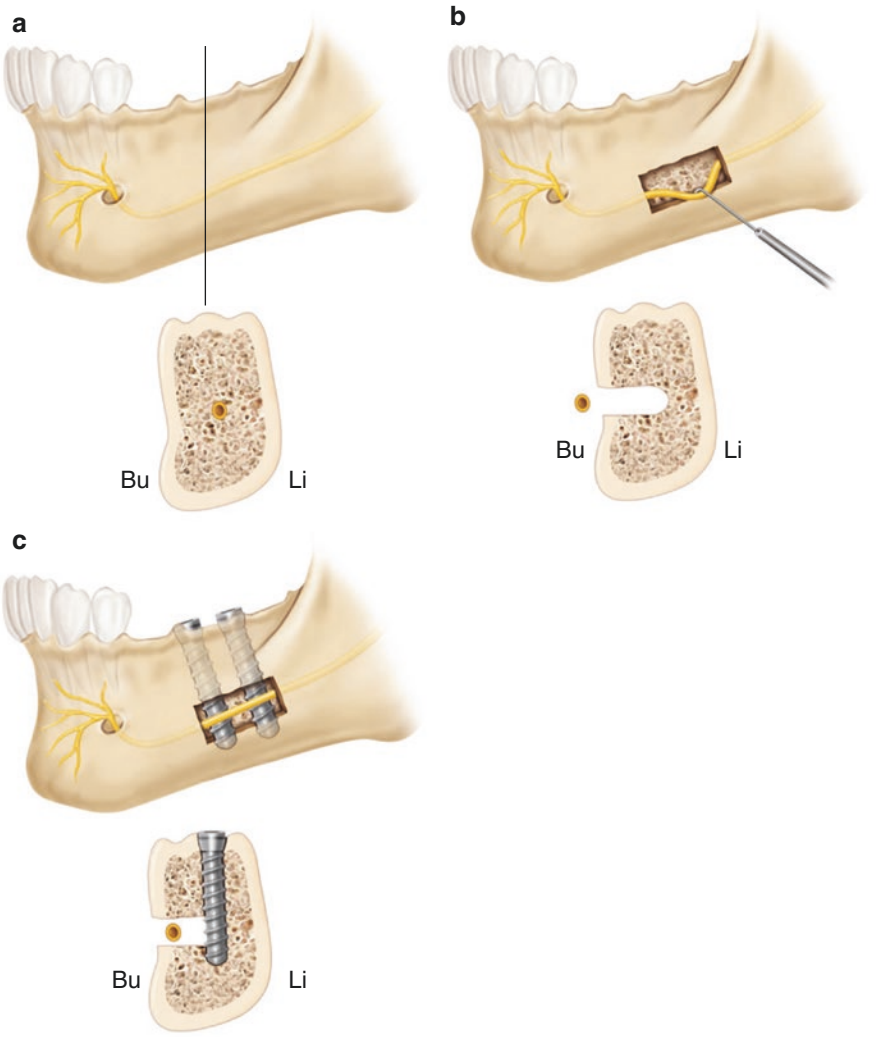
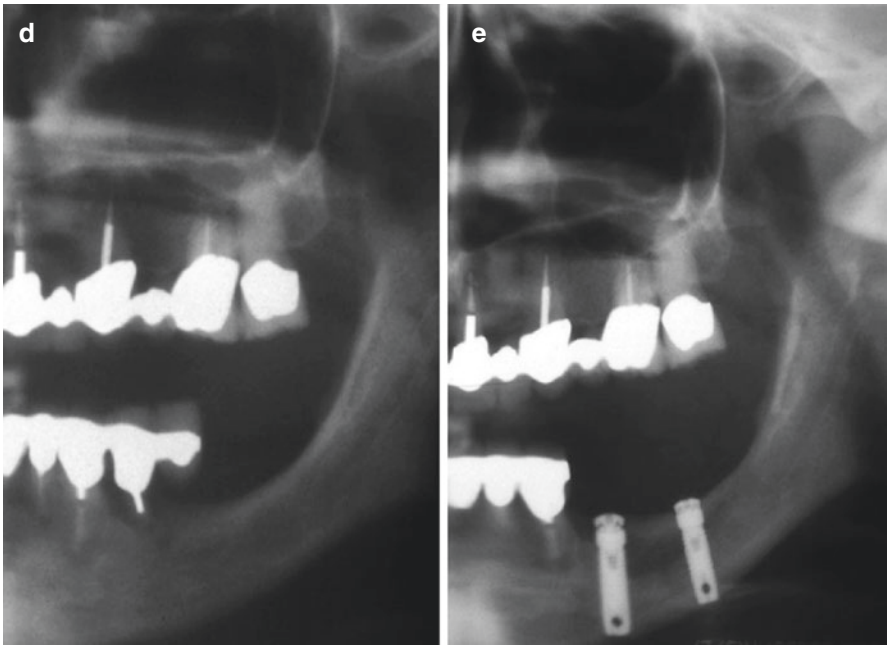


Fig. 4 (**a**) Schematic representation of anticipated site for dental implant placement, posterior mandible; (**b**) Inferior alveolar nerve lateralization; (**c**) Placement of two dental implants beyond the inferior alveolar canal; (**d**, **e**) Panoramic radiographs, pre- and post-operative clinical example. Miloro M: Trigeminal Nerve Injuries, Fig. 6.10, pp. 100–101



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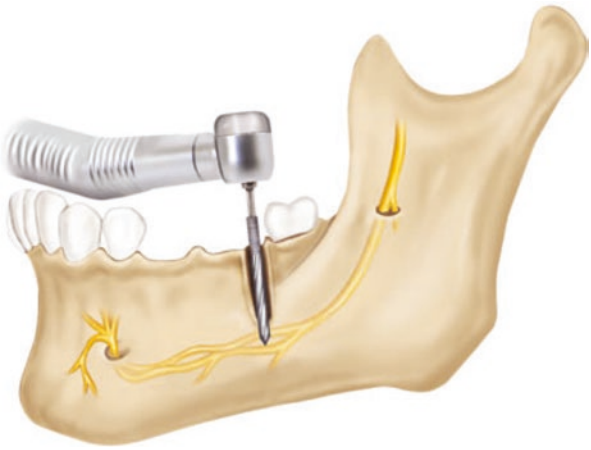


Fig. 5 Diagram of direct truama to the inferior alveolar nerve during an osteotomy. Miloro M: Trigeminal Nerve Injuries, Fig. 6.2, p. 90

existed before, causing narrowing of the canal and compression of the nerve. In such case, the onset of sensory symptoms and signs may occur weeks to months after the implant procedure [7] (Fig. 6). Such delayed injuries are difficult to prevent and predict, but should be suspected when the onset of sensory dysfunction develops late following an implant procedure.

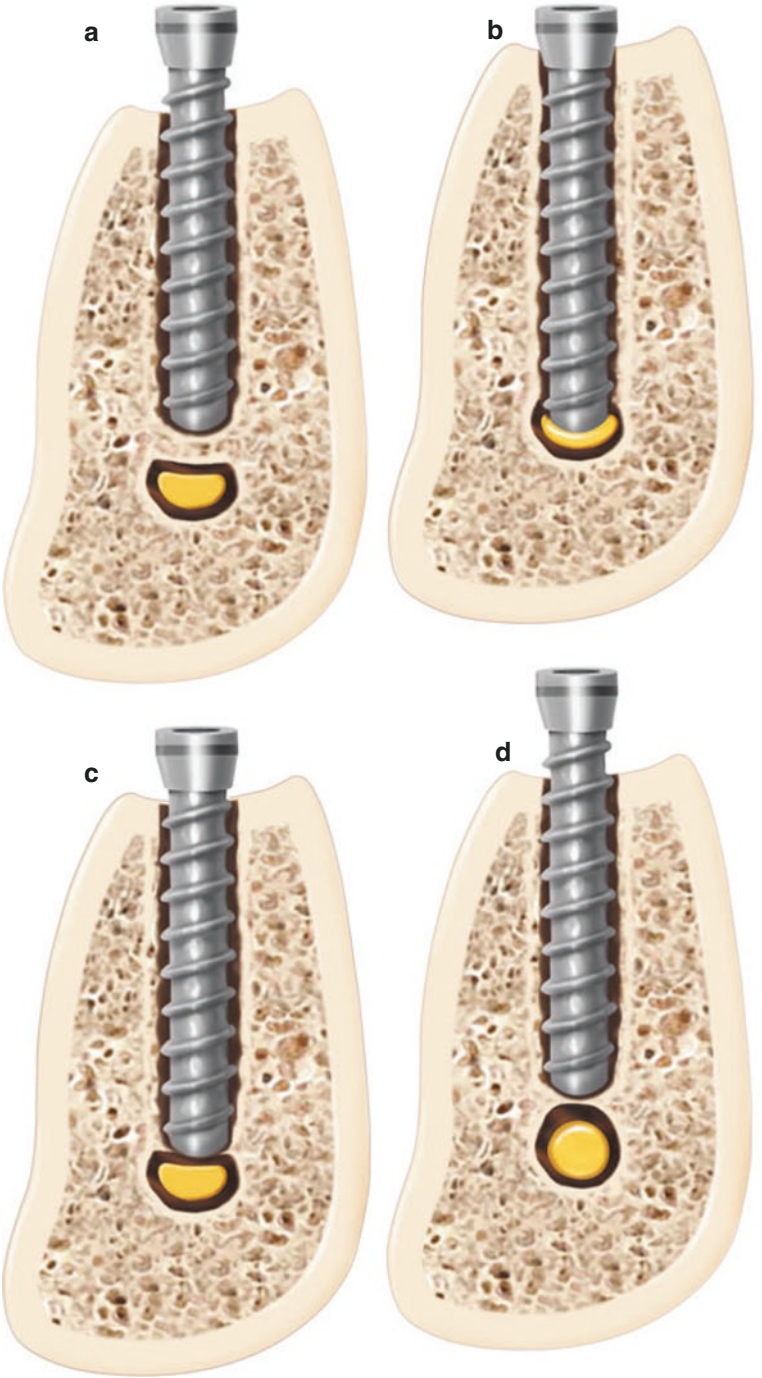


Fig. 6 (**a**) Compression and collapse of the superior aspect of the inferior alveolar canal due to implant placement beyond the planned osteotomy; (**b**) Direct injury to the inferior alveolar nerve by implant contact; (**c**) Over-insertion of implant disrupting superior wall of inferior alveolar canal resulting in *immediate* inferior alveolar nerve injury; (**d**) Over-insertion of implant disrupting superior wall of inferior alveolar canal resulting in *delayed* osseous regeneration and narrowing of the canal. Miloro M: Trigeminal Nerve Injuries, Fig. 6.4, p. 92

1.7 Medications

The perioperative administration of medications which limit the inflammatory response has been advocated for patients undergoing procedures such as dental implants, mandibular osteotomies, and lower third molar removals which are associated with a risk of nerve injury [8, 9]. It is recommended that the dental implant patient be given a single appropriate preoperative oral or intravenous dose of a corticosteroid (e.g., dexamethasone or hydrocortisone).

1.8 Bone Graft

Another etiology of nerve injury associated with implant surgery is placement of bone grafts. This can be in implant site development, ridge preservation technique, or bone grafting around implants. This is a less common cause of injury, but can be the result of impingement, compression, or crushing the IAN with overpacking or placing grafting material with excessive force. In the authors' experience, there have even been cases of material (autogenous, allogenic, xenogenic) migration around the MN and resulting in impingement of the branches exiting the mental foramen. Scarring in this area can result in neurosensory disturbance or even dysesthesia.

2 Evaluation

If a nerve injury is directly observed (open injury) during treatment, a nerve injury specialist (generally, an oral and maxillofacial surgeon who has had additional training and experience in the overall evaluation and management, including microsurgery, of TN5 injuries) should be contacted promptly and the patient referred without delay for further evaluation and treatment [10]. If no nerve injury was observed (closed injury) at the time of dental implant placement, but the patient subsequently returns complaining of numbness or pain, the nature and intensity of the painful symptoms are noted (use of a visual analog scale, VAS, is recommended). The patient is examined and responses to pain (pinprick or algometer), static light touch (cotton wisps or Semmes–Weinstein monofilaments), two-point discrimination (calipers), and moving brush stoke direction identification (cotton wisp or Von Frey hairs), so-called neurosensory testing (NST), are documented [11]. Record the history and examination findings in the patient's chart for comparison with subsequent patient VAS pain estimates and examinations, including NST, to assess progress of recovery (if any). Take a panoramic radiograph which clearly shows the implant(s) and the surrounding bone to determine the relationship of the implant to the IAC and mental foramen (MeF). If the implant is seen on the screening film to be superimposed on the IAC or MeF, a CT or CBCT scan must be obtained in order to accurately determine the mediolateral position of the implant and to ascertain if there is direct contact of the implant with the IAC or MeF. Remove or reposition the implant only if there is evidence upon imaging of encroachment of the implant upon the nerve. An implant that is not directly in contact with the IAC as seen on an imaging study should not be removed. Its removal will not have any effect on possible recovery of the nerve, and the patient will have lost a potentially functional

implant. The authors' protocol for management of closed (unobserved) TN5 injuries from dental implant surgery is summarized in Fig. 7.

The benefit of initiating corticosteroid or anti-inflammatory (NSAID) medications after a nerve injury has occurred is questionable [1, 9]. The patient is followed by the dentist at regular intervals (i.e., weekly), and a review of the progress of symptoms and reevaluation of sensory responses is done at each visit and noted in the patient's record.

Seddon's classification of peripheral nerve injuries (Sir Herbert Seddon, 1903–1977, a British neurosurgeon during and after WWII) is based on clinical findings and typical time frames, and is helpful in making a diagnosis, a prognosis, and timely treatment decisions [12].

NEURAPRAXIA is a benign injury similar to a concussion. Temporary interruption of nerve conduction without axonal discontinuity is produced. There is no demonstrable anatomic disruption of the nerve, and axonal degeneration does not occur. Spontaneous recovery is complete within 4 weeks. Surgical intervention or other treatment is not necessary.

AXONOTMESIS is a more significant injury. There is loss of continuity of some axons, but the body (e.g., connective tissue/epineurium) of the nerve remains intact. Prolonged (greater than 4 weeks) conduction failure occurs. Initial symptoms of returning sensation (tingling, itching, crawling, burning, hypersensitivity) do not begin until 5–11 weeks after injury. Eventual recovery of sensation is often less than normal, and it may be accompanied by dysesthesias. Surgical repair for removal of scar tissue, compressing bone, foreign material, or

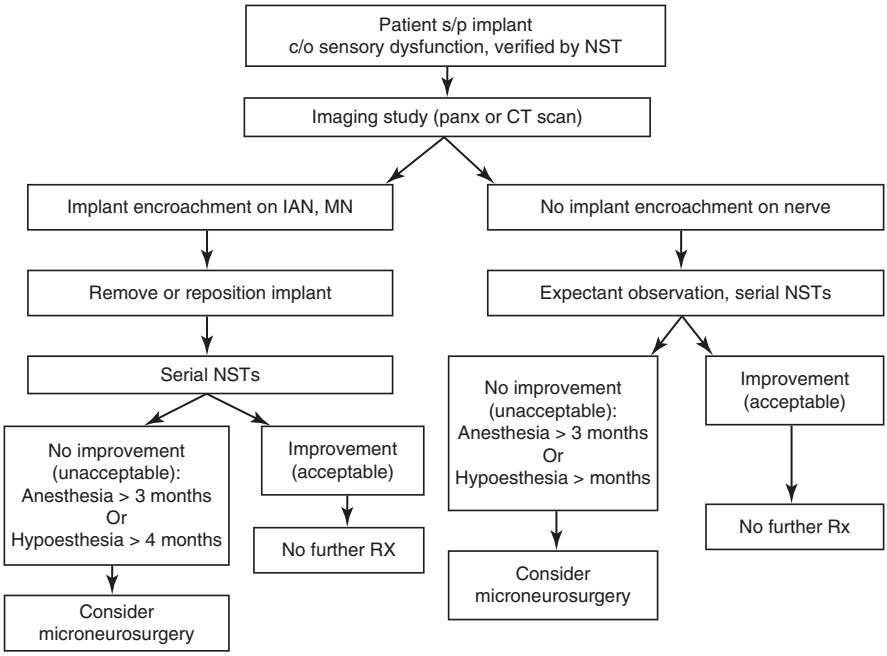


Fig. 7 Algorithm for the management of trigeminal nerve injury from dental implant surgery. Miloro M: Trigeminal Nerve Injuries, Fig. 6.1, p. 94

neuromas is often helpful in improving sensation or resolving dysesthesias, but the best results are achieved ONLY if done in a timely fashion (within 4 months in painful conditions, 6 months in others). After this time, nerve degeneration proximal and distal to the injury, deafferentation (loss of peripheral sensory input to an area of the central nervous system, CNS), and/or development of a "learned pain response" places the patient at risk to develop intractable neuropathic pain not amenable to peripheral nerve surgery, and which often fails to respond to any other treatment.

NEUROTMESIS is complete physical separation (severance) or internal physiologic disruption of the nerve with total and permanent failure to transmit sensory impulses from the periphery to the CNS. Without timely surgical repair of the nerve, there is little chance of spontaneous recovery of sensation. Permanent anesthesia is the result of nontreatment. Disabling dysesthesias often develop as well. In our clinical experience and that of others, no patients with documented total anesthesia persisting beyond 3 months have spontaneously regained significant sensation at a later date [13]. Therefore, for best chance of recovery of sensation, surgical nerve repair should be done within 3–6 months after injury before distal axonal tubules begin to atrophy and become unable to accept new axonal sprouts regenerating from the proximal nerve stump [1, 2, 10, 12, 14]. The process of axonal tubular atrophy probably becomes irreversible at between 9 and 15 months post-injury (depending at least partially upon the age and general health status of the patient). Attempted surgical repair of neurotmesis beyond this time is generally less than satisfactory, and it should not be electively delayed this long in any patient.

3 Treatment

Patients with documented closed nerve injuries which do not resolve completely within 4 weeks should be referred promptly for evaluation to a nerve injury specialist. If nerve repair becomes necessary, it can be done at the optimal time to maximize the chance for satisfactory sensory recovery. In general, the following guidelines will assist you in determining the best course of action for your patient with a nerve injury:

1. An OBSERVED (open) nerve injury should be referred WITHOUT DELAY.
2. Patients in SEVERE PAIN should be referred promptly.
3. A CLOSED (unobserved) injury can be followed and re-examined weekly for 4 weeks. If normal sensation has not returned by that time, refer the patient to a nerve injury specialist.

Microneurosurgery, or nerve repair surgery, is technically demanding and requires additional training, specialized instruments, and magnification with loupes or an operating microscope. Microneurosurgery is done in the hospital operating room under general anesthesia. Depending on the type and location of the injury, the nerve is exposed by an intraoral incision or by an inconspicuous submandibular skin incision. After the nerve is visualized, the surgeon may perform one or more of the following procedures: (Figs. 8 and 9)

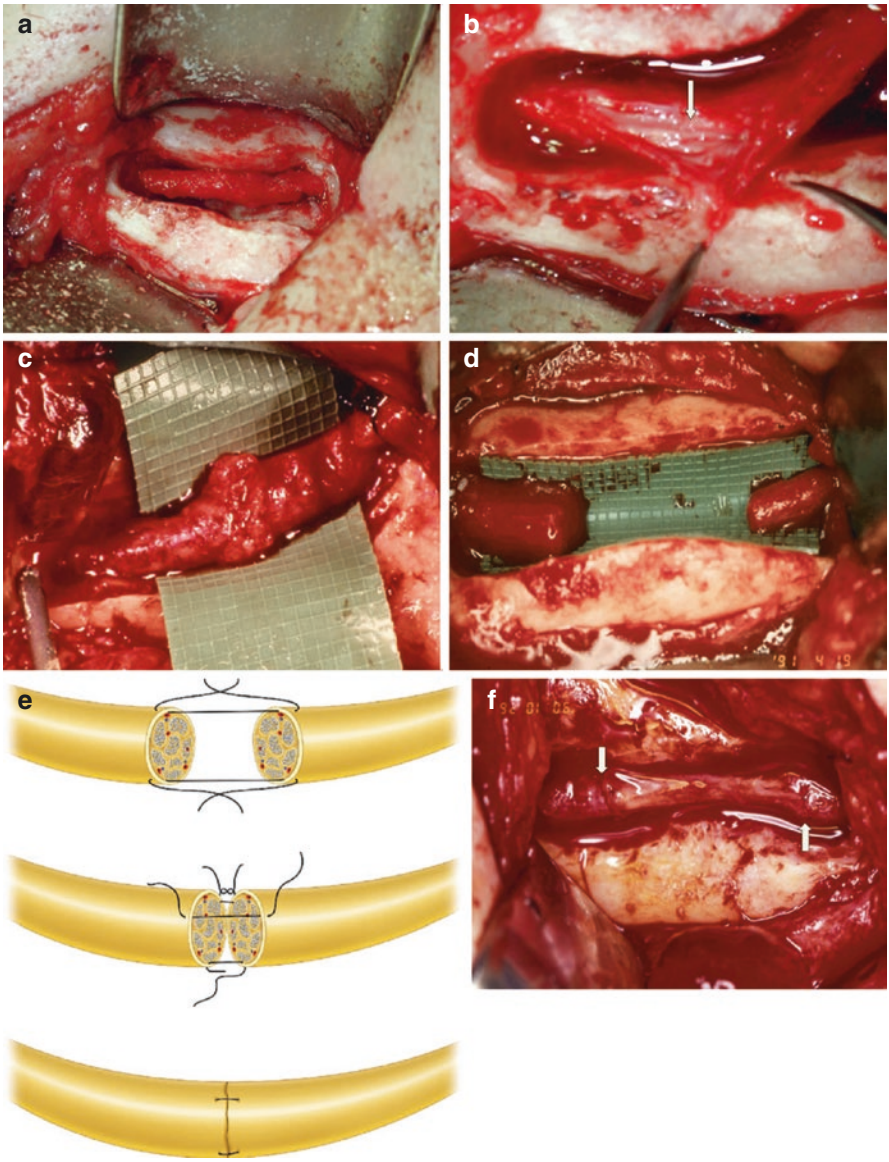
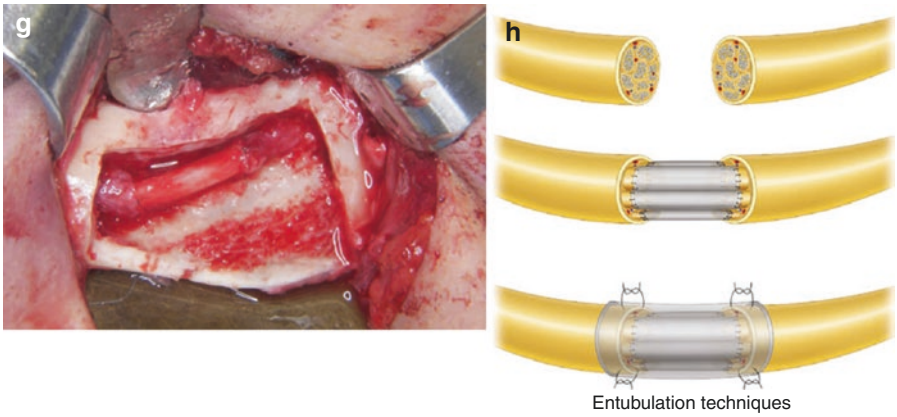


Fig. 8 (**a**–**h** only) (**a**) External decompression of the inferior alveolar nerve; (**b**) Internal neurolysis; (**c**) Neuroma-in-continuity; (**d**) Inferior alveolar nerve after excision of neuroma; (**e**) Diagram of direct neurorrhaphy; (**f**) Use of an autogenous sural nerve graft for inferior alveolar nerve reconstruction; (**g**) Use of an human nerve allograft for inferior alveolar nerve reconstruction; (**h**) Diagram of guided tissue regeneration with a conduit repair. Miloro M: Trigeminal Nerve Injuries, Fig. 6.7, pp. 97–98



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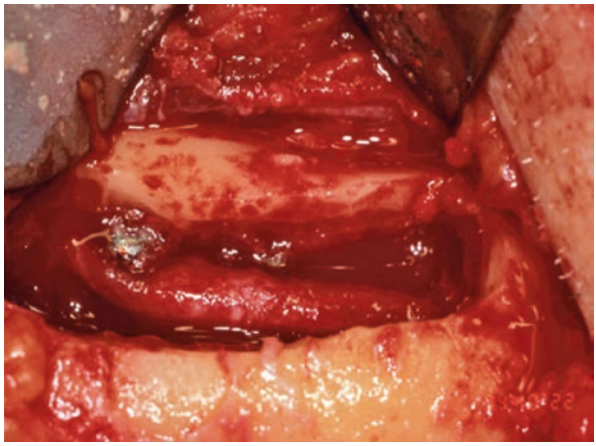

Fig. 9 Example of a dental implant impinging and deforming the integrity of the inferior alveolar nerve. Miloro M: Trigeminal Nerve Injuries, Fig. 6.8, p. 99

1. ***Decompression***: removal of surrounding scar tissue, bone or foreign material. (Note: Seldom is removal of a well-integrated implant necessary or desirable.)
2. ***Repositioning*** of the nerve away from direct contact with the dental implant(s).
3. ***Internal neurolysis***: examination of the internal structure of the nerve and removal of scar tissue from between or within nerve fascicles.
4. Excision of a neuroma or other abnormal nerve tissue followed by reconstruction.
5. ***Neurorrhaphy***: dissection and mobilization of the proximal and distal limbs of a severed nerve to allow passive coaptation and tension-free suturing of the nerve.
6. ***Nerve graft*** to reconstruct a gap in nerve continuity that cannot be brought together without tension. Whereas in the past autogenous nerve grafts (ANGs; i.e., sural nerve from the lower extremity, great auricular nerve from lateral neck), were the standard of care in reconstructing nerve gaps [15], it is now common practice to use processed homologous nerve grafts (HNGs) or nerve allografts (obtained from donors and rendered immunologically inert). HNGs spare the patient a second

surgical site from which to obtain the graft and do not require immunosuppressive therapy. In recent clinical experience they appear to have a success rate similar to ANGs [16].

The prognosis for recovery of sensation after microsurgical repair of a peripheral nerve injury is dependent upon: (a) the length of time between injury and repair (the sooner, the better), (b) the age of the patient (young better than old, especially <45 years of age), (c) the type of sensory dysfunction (restoration of sensation is easier to achieve than relief of pain, especially if chronic, i.e., >4 months duration), and (d) the technical skill of the surgeon. There is a learning curve for microneurosurgery which requires about 100 operations before a steady and predictable rate of success is possible. Success rates (based on functional sensory recovery (FSR) or a Medical Research Council System grade of 3.0–4.0) [14, 17, 18] in an experienced surgeon's hands should be 80% or better in patients operated at 6 months or sooner after injury, but may drop to 30% or less in patients operated at longer than 1 year after injury [1]. In one report on immediate repair of the IAN as part of reconstruction of ablative oncologic surgery of the mandible, all patients regained useful sensory function in the lower lip, chin and gingiva [19]. This would seem to indicate that the best results occur when the injured nerve is repaired at the time of its injury. In another retrospective study, early nerve repair (defined as <90 days after injury) resulted in a higher rate of FSR than did late repair (i.e., >90 days after injury) [14]. Therefore, the sooner the repair of the nerve, the more likely is a successful outcome. However, in instances where nerve repair is delayed for various reasons, even a repair done beyond the favorable period might result in a partial recovery which is acceptable to the patient, especially if dysesthesias are decreased or resolved.

4 Surgical Case Examples

CASE 1: A 48-year-old man presented 6 weeks after #31 dental implant placement with profound numbness to his right V3 distribution. He was referred by the primary implant provider (PIP) after 6 weeks of no improvement in his paresthesia. Subjectively, he denied any spontaneous or provoked pain in the affected area and denied any improvement in his level of numbness. His examination was significant for right V3 severe hypoesthesia without dysesthesia or hyperalgesia. His intraoral examination was unremarkable, with a healing abutment on #31 implant and normal soft tissues. A panoramic radiograph and CBCT revealed #31 implant in proximity to the right IAN canal and violation of the superior cortex of the canal. The surgeon and patient decided on neurosurgical intervention to include right IAN exploration, decompression, and repair with nerve allograft as needed through an intraoral approach (Fig. 10).

CASE 2: A 58-year-old woman presented 4 months after extraction of multiple mandibular teeth and placement of four dental implants in the areas of first molars and canines. Immediately post-op, she had numbness in her left lower lip and chin and she developed intractable pain in her left mandible with radiation to her lip and chin that was only minimally relieved with analgesics. The left, more posterior implant was removed by her PIP 7 days after placement, following which there was some diminution of her pain. At 4 weeks status post left posterior implant removal,

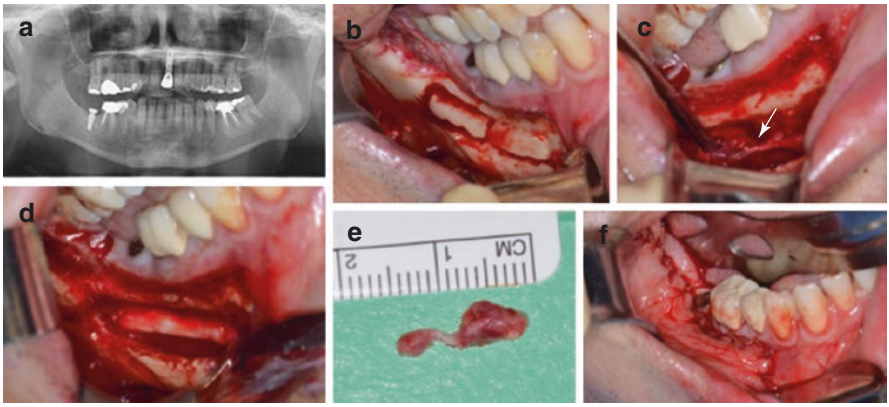

Fig. 10 (**a**) panoramic radiograph; (**b**) intraoral approach with initial osteotomy; (**c**) injured IAN with adjacent implant apex; (**d**) nerve allograft in place; (**e**) injured nerve segment; (**f**) final closure

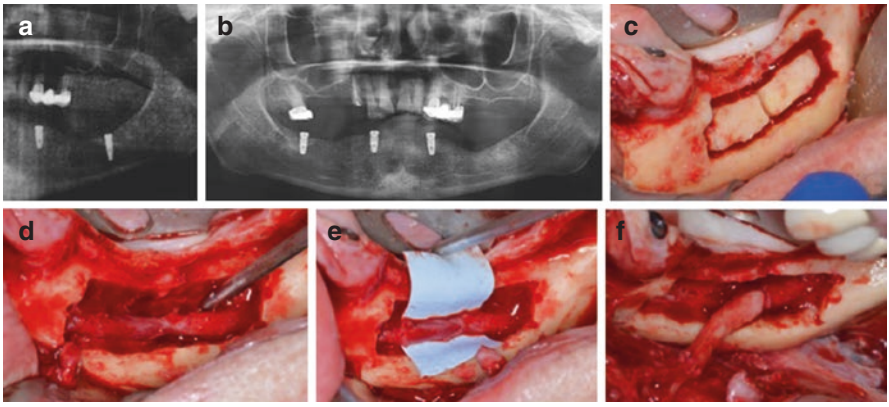

Fig. 11 (**a**) Copy of panoramic radiograph at initial implant placement; (**b**) panoramic radiograph 4 months status post explant; (**c**) intraoral approach with initial osteotomy; (**d**) injured IAN; (**e**) injured IAN with background; (**f**) coaptation of nerve allograft

she continued to have numbness and pain, and burning to her lip and chin had returned. She was referred by her PIP after nonsurgical interventions were unsuccessful. Her examination was significant for moderate hypoesthesia of the left V3 distribution with dysesthesia and hyperalgesia. Her intraoral examination was mostly unremarkable as she had three remaining mandibular implants with healing abutments and the site of the previously removed implant had healed normally. Her imaging studies were normal. The surgeon and patient decided on neurosurgical intervention to include left IAN exploration, decompression, and possible repair as needed via an intraoral approach (Fig. 11).

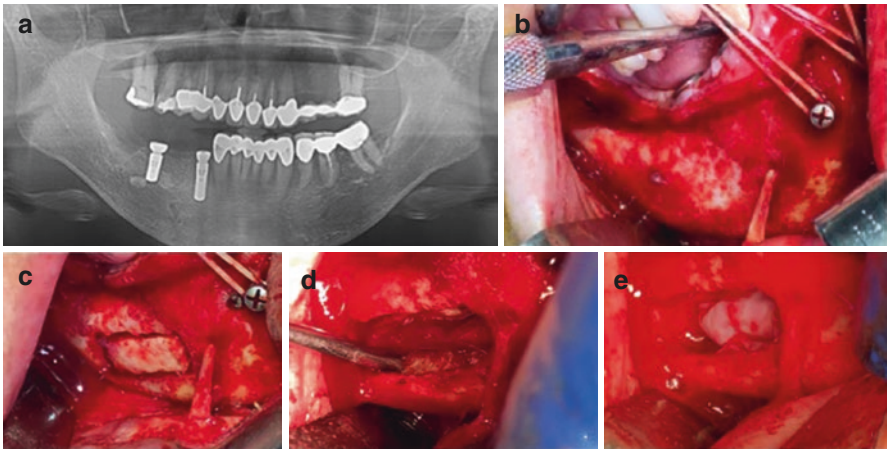

Fig. 12 (**a**) panoramic radiograph; (**b**) intraoral approach with intact mental nerve branch and evidence of bone grafting; (**c**) initial osteotomy; (**d**) IAN external decompression; (**e**) IAN protected with membrane after decompression

CASE 3: A 59-year-old woman presented 2 months after implant placement at #28 and #30 sites after staged alveolar bone grafting to the right mandible. She complained of persistent numbness and a constant severe burning sensation of her right lower lip. She was referred by her PIP after several weeks of no improvement in her symptoms. Her examination was significant for mild hypoesthesia of the right V3 distribution and severe dysesthesia. Her panoramic radiograph and CBCT displayed dental implants at #28 and #30 sites; #28 implant was unremarkable, #30 implant was in contact with the superior cortex of the IAN canal and there were areas of bony radiopacities around the canal in this area. The surgeon and patient decided on neurosurgical intervention with immediate decompression of the right IAN and possible repair as needed via an intraoral approach (Fig. 12).

CASE 4: A 33-year-old man presented 3 months after extraction of remaining mandibular teeth and placement of four dental implants in the areas of #19, #22, #27, and #31. Immediately post-op he reported numbness in his right lower lip and chin. Three days later his PIP removed the implants at the #27 and #31 sites and placed new implants at the #29 and #30 positions, but his numbness persisted. He was referred for further evaluation and treatment after unsatisfactory progress over 3 months. His examination was significant for severe right V3 hypoesthesia and hyperalgesia. His intraoral examination revealed four mandibular implants with healing abutments and normal healing of the sites of the previously removed implants. His panoramic and CBCT examinations displayed normal bony healing of previous implant and extraction sites. The surgeon and patient decided on microsurgical exploration of the right IAN with decompression and possible repair with a nerve allograft (Fig. 13).

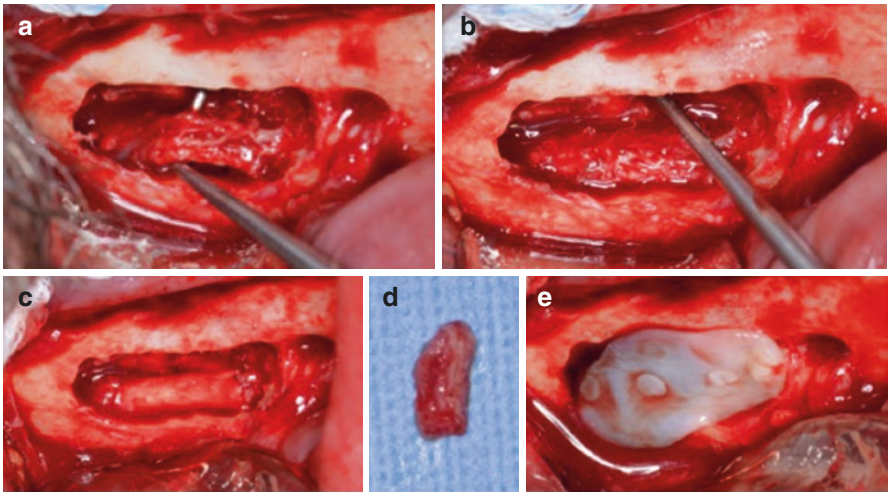

Fig. 13 (**a**) Injured nerve segment; (**b**) nerve hook within previous implant osteotomy adjacent to injured IAN; (**c**) nerve allograft in place; (**d**) injured nerve segment; (**e**) platelet-rich fibrin covering osteotomy

5 Nonsurgical Treatment and Sensory Rehabilitation

Sensory nerve injuries which do not require surgical intervention, or those recovering from a microneurosurgical operation for nerve repair, may benefit from neurotropic medications to relieve persistent neuropathic pain or hypersensitivity [20]. Physical therapy, exercise, yoga, psychological counseling, and psychiatric therapy including behavioral modification have helped many patients with post-traumatic, persistent neuropathic pain [21]. Such treatment is often provided in pain-management clinics staffed by specialists in the fields of anesthesiology, neurology, psychiatry, neurosurgery, and physiatry (physical medicine and rehabilitation).

Measures to enhance sensation and restore related orofacial functions are routinely included in the rehabilitation of the patient with a sensory nerve injury in order to maximize the end result of treatment [1]. Younger patients generally achieve better functional recovery after peripheral nerve injury and repair than mature adults (>45 years of age). Clinical experience indicates that the efficiency of tissue regeneration decreases with age. However, neuropsychological factors also influence the ability of the patient to recover successfully from a peripheral nerve injury and its repair. During the recovery process following nerve injury and repair, there may be new axonal connections with referral of sensory input to different areas of the CNS. Processing of that information requires time and practice to relearn correct interpretation of sensory input. A healing nerve's conduction speed is slowed, which requires further adaptation. Although the older patient is slower to adapt to changes imposed on the CNS after peripheral nerve injury, neuroplasticity (the ability of the brain to adapt and learn), even after traumatic injury or ablative tumor surgery, is

still viable into advanced age [22]. One can teach an old dog new tricks; it just might take longer!

The concept of sensory reeducation (SRed) was introduced by Wynn Parry in the 1960s for the rehabilitation of hand and upper extremity injuries [23]. SRed has been adapted to the oral and maxillofacial regions and shown to be successful in improving sensory function, especially in the patient's subjective interpretation of input [18, 24]. Daily SRed exercises are initiated following nerve repair, after responses to pain and light touch have been restored, and they are continued for at least 1 year, or longer if needed to achieve patient satisfaction. Long-term follow-up indicates that sensory nerve injury patients experience more favorable sensory function when SRed is included in their postoperative care regimen. SRed is also often useful in the rehabilitation of sensory function in patients whose TN5 injury did not require surgical repair.

6 Summary and Conclusions

There is a risk of injury to peripheral branches of V3 during dental implant surgery. Such injury is a known and accepted risk, and it should be included in the preoperative surgical consent process. Accurate preoperative evaluation and imaging studies and careful surgical technique can minimize this risk. If a nerve injury does occur, prompt evaluation and treatment gives the patient the best chance for a successful recovery of useful sensory function. Because the majority of dental implant patients are mature adults (>45 years of age), the potential for less than satisfactory healing or development of chronic neuropathic pain is magnified, especially if not evaluated and treated in a timely fashion according to the protocol discussed above. In developing a useful philosophy regarding the treatment of peripheral nerve injuries in general, and TN5 injuries in particular, two statements from the past literature on this subject have stood the test of time and govern our current principles of peripheral nerve injury management. In 1947 Seddon wrote, "If a purely *expectant* (i.e., observation only; emphasis by the authors) policy is pursued, the favorable time for operative intervention will always be missed…" [12]. In 1992 Colin and Donoff advised, "We emphasize that the current standard of care for these complex injuries is *early referral* to clinicians *familiar with their management* (emphasis added by the authors)" [25].

The incidence of nerve injuries associated with dental implants is unknown, although nerve injury specialists (including the authors' practice) see such injuries frequently. Reliable statistics are lacking at present. A typical article in the literature contains an uncontrolled study with small numbers of patients and inadequate data on sensory evaluation from a single practice or center [26]. It seems logical that when a new surgical procedure is introduced, practitioners' early experience is fraught with more complications, which hopefully diminish in frequency and severity, as the "learning curve" is surmounted. The development of a national dental implant data collection center to which all patients who receive dental implants would be registered and followed by their practitioners, with mandatory reporting

of complications (including nerve injuries and/or whether an implant was removed), would do much to elucidate the magnitude of dental implant-associated TN5 injuries and provide information which might assist nerve injury specialists in their care.

Acknowledgment *Disclaimer*: The views expressed in this material are those of the author(s) and do not reflect the official policy or position of the U.S. Government, the Department of Defense, or the Department of the Air Force.

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Complications of Sinus Grafting and the Atrophic Maxilla

Ali Hassani and Omidreza Fazli salehi

1 Background

Sinus grafting techniques have been used by surgeons for more than four decades. Throughout this time significant progress has been made to make these procedures safer, less aggressive, and with more predictable results [1]. Technological breakthroughs such as cone-beam computed tomography and piezoelectric surgery have contributed massively to this cause. Nevertheless, working on the sinus membrane is a task of great finesse and complications may at times arise even in the hands of experienced clinicians.

Zygomatic implants and pterygoid implants were first introduced in the late 1980s to help provide an alternative to grafting, facilitate immediate loading after implantation, and occlusal rehabilitation of patients with maxillary defects following ablative tumor surgeries [2, 3].The Nazalus implant is a more recent design as a solution to the limitations of zygomatic and pterygoid implants, utilizing the dense cortical bone in the lateral nasal bone [4, 5]. Aside from the propensity for surgical complications in these techniques—particularly for novice surgeons—prosthetic rehabilitation of an implant with a suboptimal emergence profile and position can be quite arduous. With proper examination and planning, the incidence of complications can be kept to a minimum and those that do occur can be readily managed.

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2 Sinus Grafting

Of all the bone augmentation techniques employed for site preparation prior to dental implantation, sinus elevation surgery has the most predictable results. Evidence reporting on the remarkably high success rate of implant success after sinus elevation surgery and the scarcity of complications with this procedure is a testament to this claim [6].

2.1 Lateral Window Technique

An atrophied maxilla with posterior bone height of less than 4 mm probably warrants the use of open sinus elevation by a lateral window technique. Sinus complications mostly occur due to the potentially complex anatomy of the surgical site (membrane being too thin or too thick, presence of septa, cysts, thick lateral sinus wall) insufficient clinical and para-clinical patient evaluation, and iatrogenic mishaps. Perforation of the Schneiderian membrane is reportedly the most common intraoperative complication with intraoperative bleeding being a distant second followed by perforations in the buccal flap, injury to the infra-orbital nerve, implant displacement into the sinus, perforation of the orbital wall, and obstruction of the ostium [7].

Though seasoned practitioners can manage most complications in this realm with ease, the adage "Prevention is better than the cure" highlights the approach we should take toward this procedure and its potential complications.

2.1.1 Preoperative Work-up

Careful presurgical examination of patients for a history of previous medical conditions that could have an impact on sinus elevation surgery is a must. A history of blood diseases, radiotherapy in the head and neck region, autoimmune diseases, and taking antiresorptive medication (such as bisphosphonates) often require further examination and consultation with medical specialists in different disciplines before the surgery.

Next, to avoid uncalled-for postsurgical complications, it is wise to carry out a comprehensive clinical and radiographic assessment of the sino-nasal complex. Patients should be asked if they have ever experienced allergies, sinus infections, facial trauma, and whether they sense a constant obstruction in one or both of their nasal passages. The cone-beam CT acquired for evaluating bone height and width should also be examined for the existence of abnormalities in the sinus wall and cavity. A medical CT scan of the nose and paranasal sinuses yields the most information about the anatomy of the sino-nasal complex among other radiographic modalities without the ability to assess the width and height of the alveolar bone (Figs. 1, 2, and 3).

Previous surgical procedures on the maxilla and the sino-nasal complex should also be carefully noted and evaluated. If any of these conditions exists, consulting an ENT specialist would be a prerequisite to sinus surgery. Cases of acute sinusitis

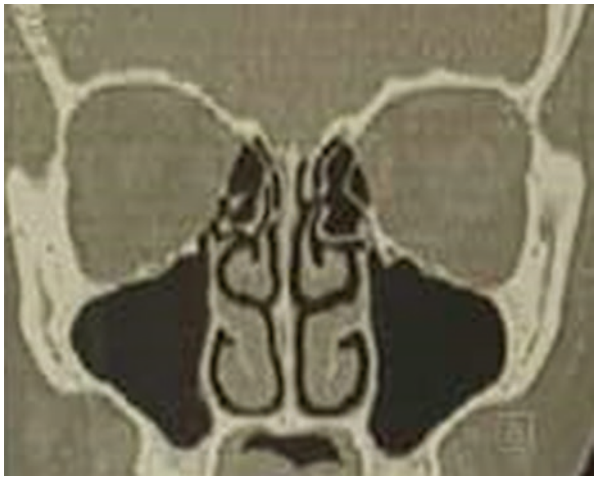


Fig. 1 Coronal view CT scan of a patient with healthy paranasal sinus structures. Maxillary sinuses are radiolucent with no signs of mucosal thickening, pseudocysts, and air-fluid levels. The sinus ostium opens to the middle meatus at the superior one third of the antrum

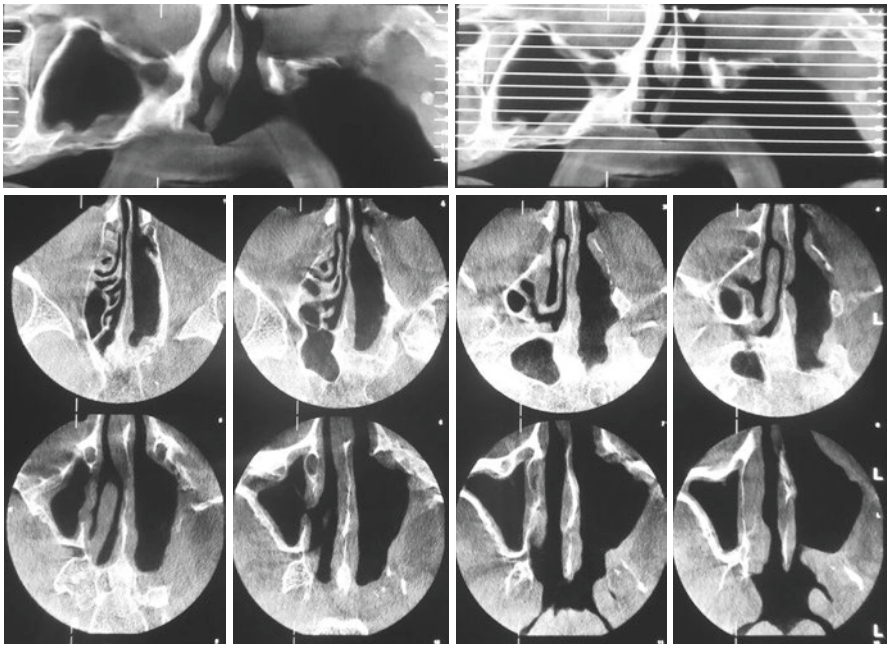


Fig. 2 Cone-beam CT scan of a patient who has had partial maxillectomy due to an osteoradionecrosis unresponsive to treatment, shows the absence of left antrum and left maxillary basal bone. The right alveolar bone is severely atrophied and mucosal thickening in the left antrum is evident

with air-fluid levels in the CT scan can usually be treated by medication and sinus surgery can be scheduled when the signs and symptoms have resolved. In the case of chronic sinusitis with frequent periods of exacerbation, referring the patient to an ENT specialist would be prudent. If sinus elevation is done properly on a healthy

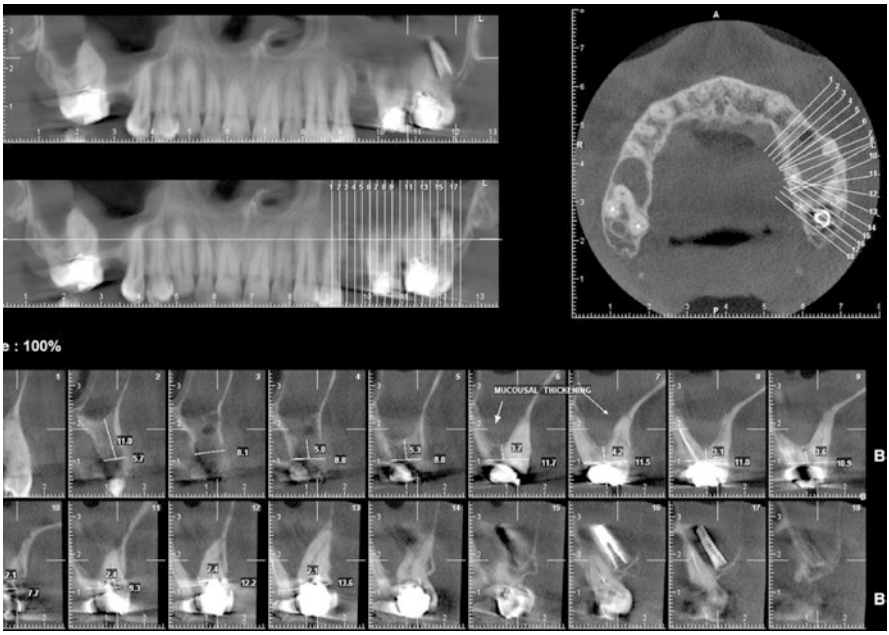


Fig. 3 Cone-beam CT scan of a patient with an implant inserted at the left upper second premolar socket displaced into the left maxillary sinus. Without a CBCT evaluation, estimating the correct position of the displaced implant would have been very difficult. Note the Oro-antral fistula at the implantation site, mucosal thickening in the right antrum, and air-fluid levels in the left antrum

sinus, the subsequent graft or implant placement would not involve the sinus, or be "Intra-sinus" per say, and does not interfere with sinus function; however, when performed on an unhealthy sinus, the same procedure might lead to ostium blockage followed by fluid stagnation and bacterial colonization. Also, matters would be much more difficult to manage in an unhealthy sinus if complications such as sinus perforations do arise. In the case of chronic sinusitis irresponsive to medication, functional endoscopic sinus surgery (FESS) is deemed necessary prior to sinus elevation. It might be wise to attain a follow-up CT to ascertain the alleviation of symptoms before initiating sinus elevation.

The patients' social and behavioral history should not be taken for granted. A history of substance abuse significantly decreases wound healing potential and contributes to skin and mucosal breakdown. Cocaine sniffing can potentially perforate the hard palate and cause sinusitis [8]. A recent systematic review and meta-analysis by Moraschini and Barbosa confirms cigarette smokers are in a greater risk for bone loss and implant failure after dental implantation [9].

Preoperative and postoperative antibiotic therapy is warranted for all patients requiring sinus surgery. Antibiotic prophylaxis coupled with aseptic surgical conditions (rinsing with 0.2% chlorhexidine for 30–60 s right before the surgery, prepping the perioral skin with povidone-iodine and using sterile drapes and gloves)

Table 1 Prophylaxis and postoperative drug therapy in sinus elevation patient [10]

	Prophylaxis	Postoperative therapy
Patients not allergic to penicillin	Amoxicillin (875 mg) with clavulanic acid (125 mg) twice per day by mouth starting 24 h before surgery.	Amoxicillin (875 mg) with clavulanic acid (125 mg) twice per day by mouth for 7 days.
Patients allergic to penicillin	Clarithromycin 250 mg twice per day and metronidazole 500 mg three times per day by mouth starting 24 h before surgery.	Clarithromycin 250 mg twice per day and metronidazole 500 mg three times per day by mouth for 7 days.

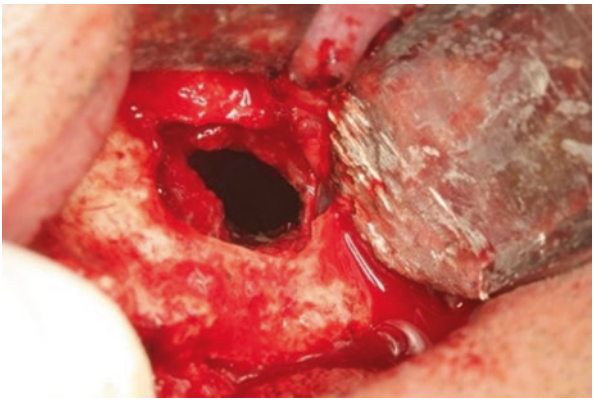


Fig. 4 Perforated Schneiderian membrane. Note the remnants of the membrane surrounding the perforation

helps keeping the infection rate to a minimum. According to Testori et al. the most common regimen for prophylaxis and postoperative drug therapy in sinus elevation patients is mentioned in Table 1 [10].

2.1.2 Intraoperative Complications

Schneiderian Membrane Perforation

As mentioned earlier, Schneiderian membrane perforation is the most prevalent intraoperative complication in sinus elevation surgery (Fig. 4). This could occur at any time during the surgery; even if the membrane is kept sound during the lateral window preparation and elevation of the membrane, uncontrolled pressure while placing graft material can lead to membrane tear. In cases where a previous Oro-antral fistula has healed only by soft tissue, perforation might happen in the early flap elevation stage. Also, in case a natural fenestrations of the lateral sinus wall exists, aggressive application of the periosteal elevator can tear the Schneiderian membrane attached to the periosteum through the fenestration (Fig. 5).

Expert practitioners have claimed to have a perforation rate close to 25%, where as other reports have mentioned perforation rates as high as 56% [11]. Regardless of the surgeon's experience and the technique being used, several factors contribute to a higher rate of membrane perforation.

Primarily, membrane thickness affects the rate of perforations during surgery. In the lateral window approach, the occurrence of perforations is at its lowest when

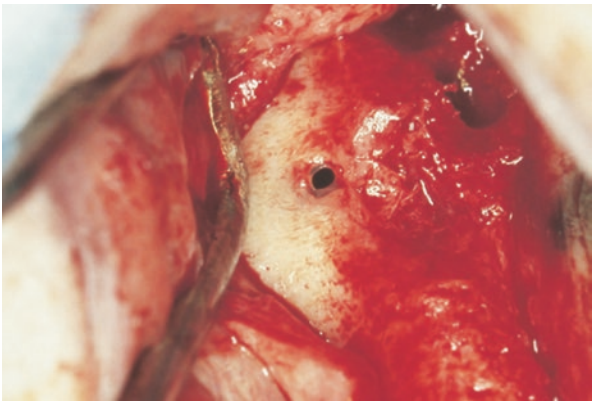


Fig. 5 Fenestration of the lateral wall of the sinus wall as a normal variation can be seen after elevation of the mucoperiosteal flap. Perforation of the membrane probably could have been prevented by more gentle application of the periosteal elevator while elevating the flap

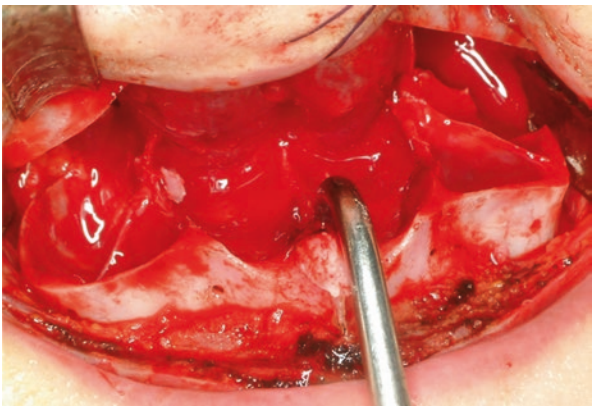


Fig. 6 Anatomy of the nasal floor and the maxillary sinuses can be seen after a Lefort I osteotomy in this patient. The hook retractor is placed posterior to the anterior nasal spine. Note the septa present in each sinus cavity

the membrane thickness is 1–1.5 mm. Membrane thickness, more than 2 mm or lower than 1 mm, significantly increases the rate of perforations [12]. Another factor is the presence of septa. According to Irinakis et al. with the presence of an interfering septum the incidence of sinus membrane perforation was 44.7% compared to only 2.4% when no septa was visualized in the preoperative CBCT (Figs. 6 and 7). The type of septa extending mediolaterally (bucco-lingually) was related to the highest incidence of membrane perforation. The third factor is the sinus width, or better said, the angle that the medial and lateral sinus. Cho et al. showed that as the angle between the medial and lateral sinus walls decreases (less than 30°) at the narrower anterior portions of sinus, the risk of membrane perforation increases (62.5%) [13].

Another angle measurement highlighted by Chan et al. in 2013 is the angle in the palatonasal recess, where the alveolus meets the medial sinus wall (Fig. 8). The incidence of membrane perforation increases if this angle is acute and is less than 10 mm away from the sinus floor [14]. It is, therefore, prudent to keep the sinus elevating instrument in contact with bone at all times in this region to prevent trapping and tearing the membrane.

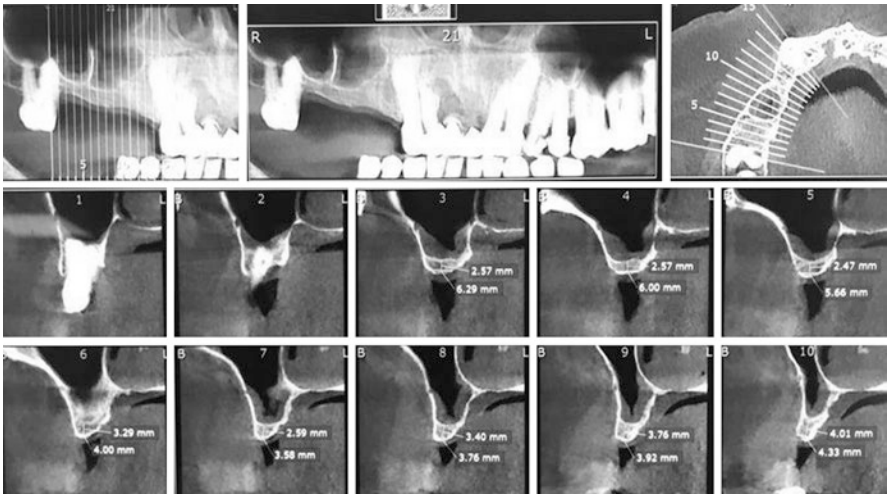


Fig. 7 Septa in the right maxillary sinus. In this case the septa has no attachments to the lateral sinus wall

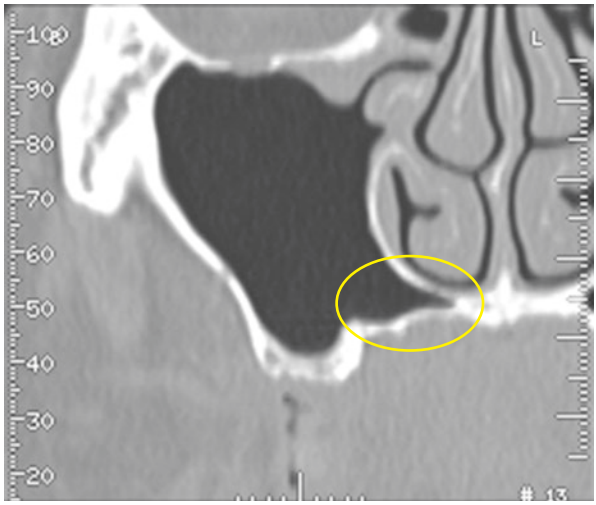


Fig. 8 The acute angle between the sinus floor and the medial sinus wall, increases the risk for sinus membrane perforation during sinus elevation surgery in this region

2.2 Prevention

There are two elements pertaining to successful prevention of sinus membrane perforation in sinus grafting.

First and foremost, knowledge. To elaborate: knowledge of the patients' sinus anatomy and health, and the clinician's own level of expertise. Almost all the aforementioned factors regarding sinus diseases, membrane thickness, existence of septa, and anatomical angles can be thoroughly investigated three dimensionally in a

pre-operative CT scan or CBCT. Untrained clinicians might not be aware of the importance of these details and only focus on bone width and height for implant placement instead. It is not uncommon for a trained yet unseasoned surgeon with a multitude of successful surgeries in his/her resume to overlook the signals of a difficult surgery in the pre-op CBCT only to end up having to manage a complication which could have been avoided. If the clinician comes to the conclusion that the level of challenge of the case surpasses his or her expertise, it is sensible to consult an experienced specialist or refer the patient to a more experienced colleague.

Second, preparation. Piezoelectric surgery devices with the ability to selectively cut through hard tissues are now being extensively advocated for safe sinus elevation surgery [15]. It is widely known that diamond burs don't easily entrap the thin membrane when cutting through the lateral sinus wall, compared to carbide burs. The DASK drilling system by Dentium utilizes a series of dome-shaped diamond burs which is supported by many authors for reducing perforations rates significantly (Fig. 9). Apparently, using these devices does not make up for haphazard surgical planning and execution, but having safe equipment ready for surgeries with greater risk for membrane perforation is strongly recommended [16].

If a defect at the crest or the lateral sinus wall exists due to previous surgical failures, tooth extraction or trauma, care must be taken to elevate the flap in a split-thickness fashion. In such a case, the periosteum lying under the surface mucosa will remain attached to the scarred Schneiderian membrane at the defect site and can later be elevated with care. The elevation of this complex is not simple; the remaining periosteum just outside the defect is still firmly attached to the lateral sinus wall and also the scar-like attachment between the periosteum and the sinus membrane might create a different feel for the surgeon during the elevation. Trimming the periosteum painstakingly around the defect and expanding the defect window with piezo surgery or diamond burs can help minimize the risks discussed.

Once the existence of septa in the sinus is established in the radiograph, several measures can be taken to avoid membrane perforation. Only in rare occasions a septa of sufficient height divides the antrum to two separate chambers at the level of the lateral window. Regardless of the position and height of the septa, membrane

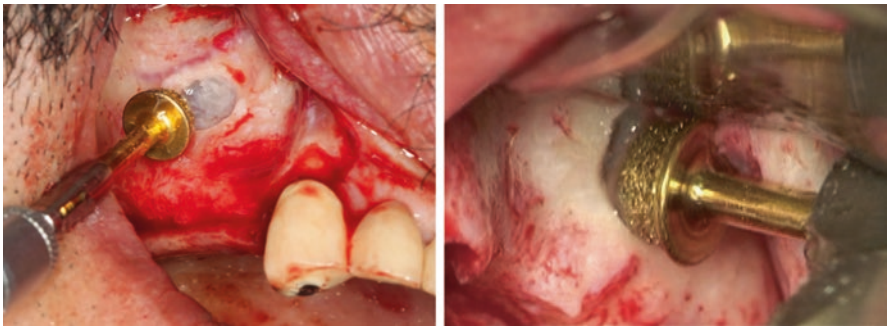


Fig. 9 Round diamond burs in the DASK system can be used to drill out the lateral sinus wall without traumatically engaging the sinus membrane

elevation tends to be more arduous where the sinus floor and the septa collide. The common instruments used for membrane elevation might not adapt to the bony walls as they should around the septa. The most important principle is to work with good access and visibility which allows for better adaptation of the hand instruments around the septa. The standard lateral window design usually places the window 3 mm above the sinus floor and 3 mm distal to the nasal wall. The lateral wall can be completely drilled out—as is with the DASK system—or a bony island can be saved attached to the membrane and elevated with the membrane. If septa exists, however, the lateral window should be completely drilled with diamond burs. One proposed lateral window design is the double window design with a thin portion of the lateral sinus wall remaining just adjacent laterally to the septa (Fig. 10). Though proven to be effective, sometimes locating the exact position of the septa and therefore the remaining lateral wall border in the double window design cannot be executed with precision, resulting in inadequate access in one or both windows. In reality, there is little if any advantage in keeping a thin portion of the lateral window adjacent to the septa undrilled and better access can be gained with a long window providing access to the septa both anteriorly and posteriorly (Fig. 11). Preferably the window should extend superiorly enough above the superior portion of the septa. The area most prone to membrane perforation is the angle between the septa and sinus floor, so it is advisable to elevate the membrane from the other areas first (Fig. 12).

One technique used by the author in elevating the membrane on the septal walls is to provide adequate access by the mentioned lengthy window and carefully detach the membrane with hand instruments in the first 2 mm of the angle produced by the septa and sinus floor. Then, a fine cottle osteotome can be cautiously used to detach the septa and the membrane remaining attached to it from the sinus floor. Sometimes using a mallet would be unnecessary as a thin septa often gives in easily to the

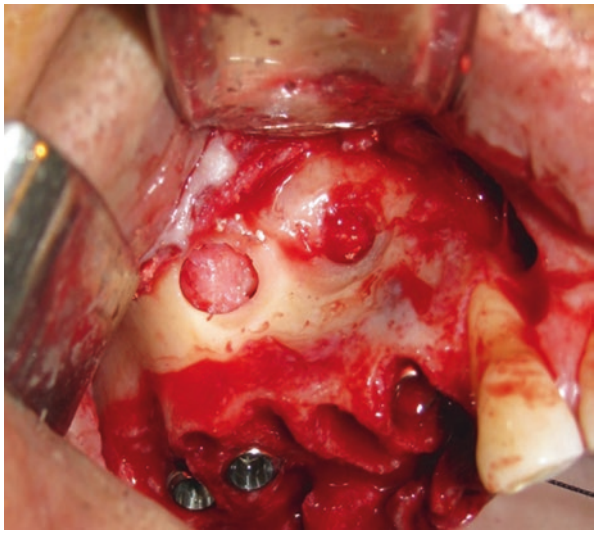


Fig. 10 Double window lateral wall osteotomy to elevate the sinus membrane around a septa in the antrum. In this design the portion of the lateral wall adjacent to the septa is not drilled

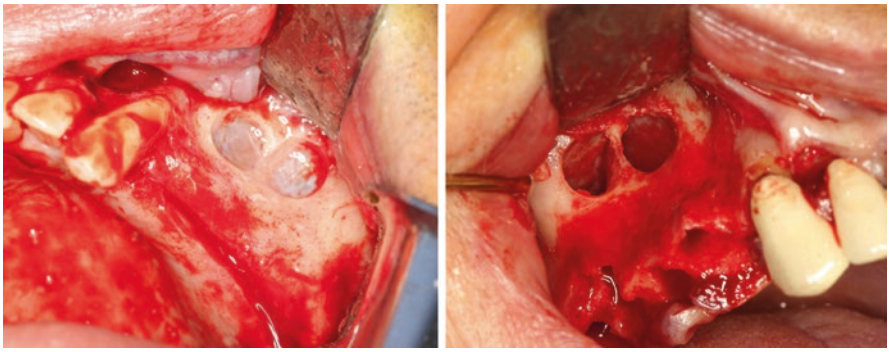


Fig. 11 Examples of extended lateral window preparations for sinus elevation surgery adjacent to sinus septa

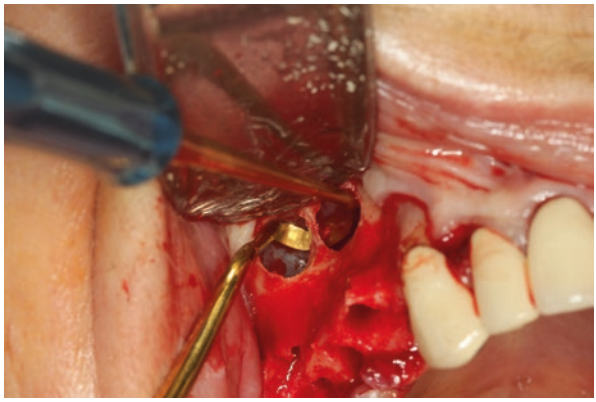


Fig. 12 Sinus membrane attached to the septa is most prone to perforation. Thus the membrane is elevated from medial and lateral aspects of the lateral window first and the membrane attached to the septa is attended to last

ostetome. The ostetome blade should be kept with a slight angle toward the sinus floor and extra care should be taken not to use excessive force.

2.3 Management of Sinus Membrane Perforation

The effect of sinus perforation on the course of treatment and its success depends on the size and the location of the perforation. When particulate grafts are being used, unrepaired sinus membrane perforations can lead to loss of graft material into the sinus cavity, infection, Oro-antral fistula, and other sequelae [17]. Proper elevation of the sinus membrane results in better blood supply for graft compartments, as the bony sinus walls are the main source of this blood supply rather than the sinus membrane. Attempts have been made to classify sinus membrane perforations and suggest treatment protocols accordingly by several researchers. Fugazzotto and Vlassis have offered a simplified classification of sinus membrane perforation based on the location and the size of perforations [18]:

Type of Perforation	Description of Perforation
Class I	Produced in the most apical part of the window
Class IIA	Produced along the lateral or coronal wall of the window; the sinus extends 4 to 5 mm proximal to the perforation
Class IIB	Differs from the previously mentioned classes because the perforation is located at the limit of the maxillary sinus; therefore the osteotomy cannot be enlarged to expose intact membrane
Class III	Produced in any part within the window extension

The decision a practitioner makes once membrane perforation happens varies based on the size and location of the tear from no treatment to postponing the entire procedure for 6–9 months. One should remember a perforation makes the membrane more vulnerable and a small tear might easily expand in size with much less force. Still, once the membrane is perforated the clinician must try to work with finesse to elevate the surrounding sound portions of the membrane from around the perforation. It is prudent to extend the lateral window to expose more intact membrane around the perforation. Also the authors believe it is best to first continue sinus elevation away from the perforation distally and then toward the sinus floor and lastly, mesially. At times, this is the only maneuver required. If the perforation is bigger or located at the mesial or lateral sinus walls with not enough intact membrane around, other measures should be employed. In general, application of a bioabsorbable membrane is the most common approach to repair sinus membrane perforations (Fig. 13). The absorbable membranes used for this purpose should not be thin and too soft as they might become easily displaced and ineffective, specially when they become wet.

2.3.1 Small Perforations (Less than 2 mm Diameter)

As mentioned, the clinician must work its way meticulously to elevate the sound membrane around the perforation. As the membrane is elevated it "folds on itself" sealing a small perforation at its apical end. To make sure no route to the sinus exists, a bioabsorbable membrane can be placed like a patch underneath the perforation. The membrane should well extend around the perforation and on intact membrane.

If a small perforation is created adjacent to the lateral sinus walls where adequate intact membrane does not exist around the perforation site, applying a bioabsorbable membrane becomes mandatory.

2.3.2 Perforations (2–10 mm Diameter) with Surrounding Intact Membrane

In this case, elevating the intact membrane becomes more challenging as bigger tears affect the vulnerability of the membrane to a greater extent. Once the membrane is soundly elevated around the perforation, the folding of the membrane does not completely seal a perforation of this size. In this case, applying a bioabsorbable

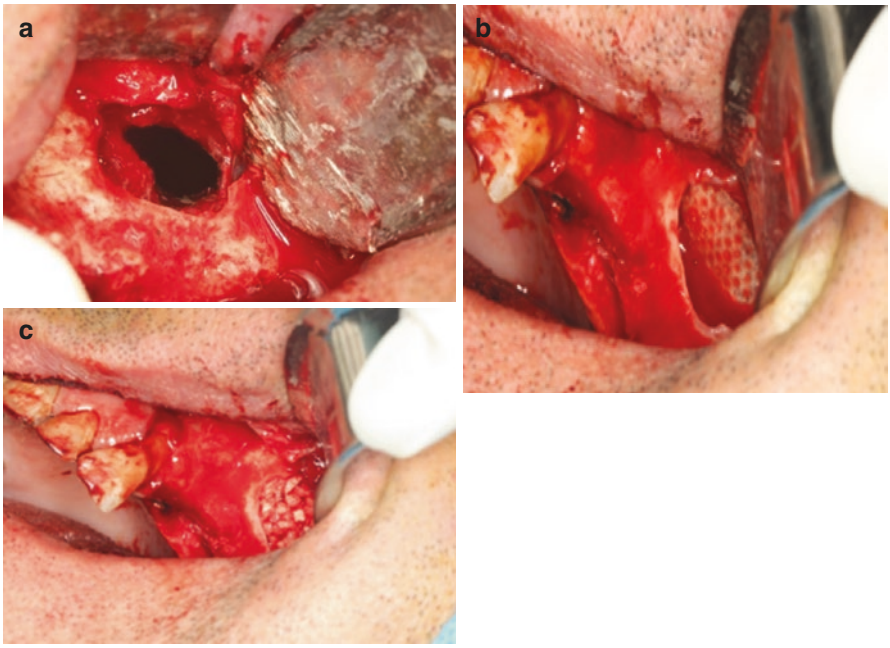


Fig. 13 Membrane perforation with remnants of the membrane attached to the sinus wall (**a**). The lateral window is extended and sound membrane around the perforation is elevated from the surrounding sinus walls. A bioabsorbable membrane is used to cover the perforation like a patch (**b**). The sinus is grafted next (**c**)

membrane is a must. The membrane used must remain stiff after absorbing fluids and it should extend beyond the perforation and lean on sound sinus membrane.

2.3.3 Perforations with 2–5 mm Diameter Close to Lateral Sinus Walls

The proximity of the perforation to the sinus walls leaves no intact membrane around the perforation. The primary approach in this case might be to use a bioabsorbable membrane. Nevertheless, care must be taken not to allow the membrane to be displaced medially while grafting is done; This is most probable if the membrane used is too thin and loses its vigor when wet.

Another approach is using sutures [19]. If the quality of the sinus membrane is acceptable, the membrane margins are gently released as much as possible. Two holes are then made 3–4 mm apart by a small fissure bur in the lateral sinus wall adjacent to the access window. Next, a 4–0 absorbable suture with a round needle is passed through one of the holes from the outer surface into the sinus and then passed through 2 points reasonably away from each other in the membrane to minimize tension and prevent further tearing (Fig. 14). The suture is then passed through the

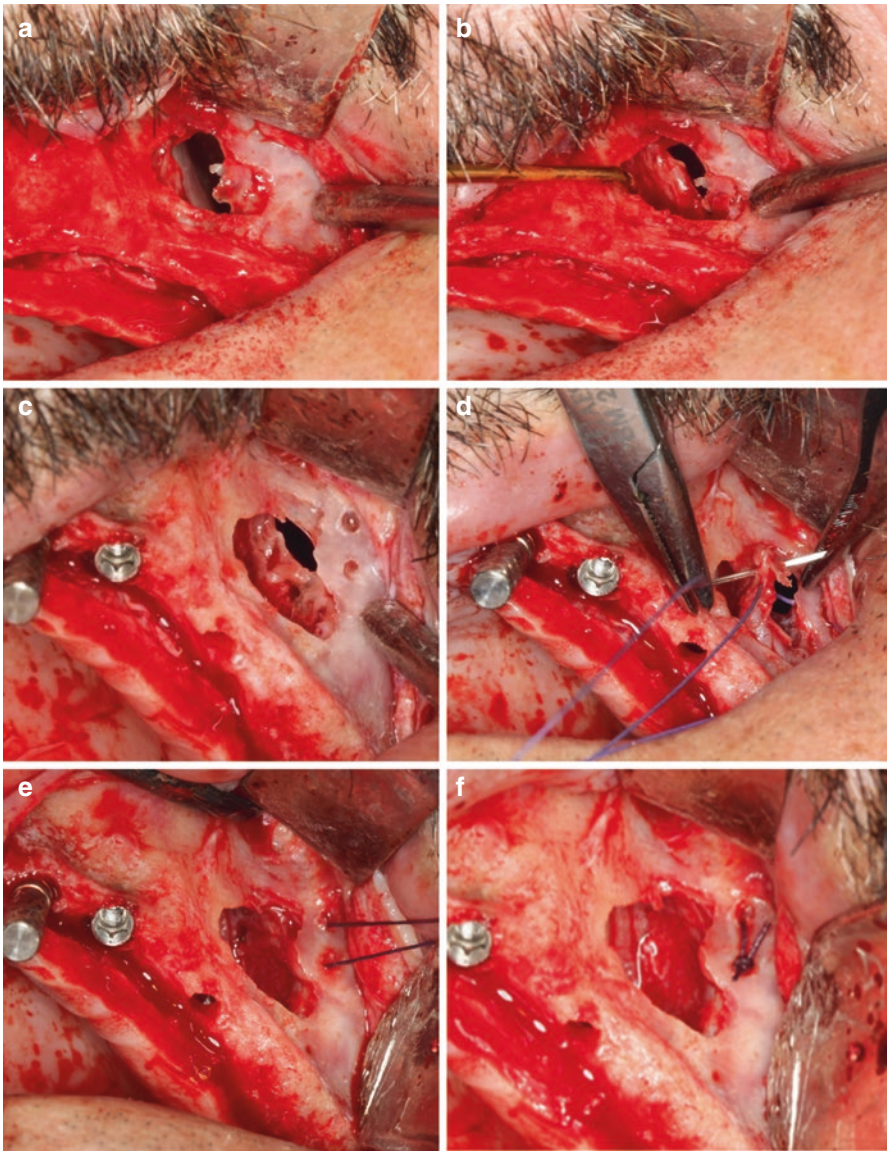


Fig. 14 Managing a membrane perforation adjacent to the lateral sinus wall by sutures. The intact membrane around the perforation is elevated (**a**, **b**). Two holes are prepared in the lateral sinus wall using fissure burs (**c**). A bioabsorbable 4–0 suture is introduced to the sinus through one of the holes and then passes through the elevated Schneiderian membrane in two places (**d**). The needle is pulled outside the sinus through the other hole and a knot is tied to pull the elevated sinus membrane over the perforated site, sealing the sinus cavity (**e**, **f**)

other hole, exiting from inside out and the knot is tied outside the sinus, pulling the membrane toward the sinus wall like a horizontal mattress technique. Clinicians must make sure they have the right instruments and skillset before using this approach as mishaps in this technique might make matters worse and beyond repair. This technique can also be used for class 1 Fugazzotto perforations when the perforation diameter is less than 5 mm. Once sutures are used for fixing the membrane perforation, application of synthetic membranes or biologic membranes such as platelet-rich membranes (PRF) are recommended.

2.3.4 Perforations with 5–10 mm Diameter Close to Lateral Sinus Walls

The increased size and difficult location of these kind of perforations might render the previously described measures ineffective. Sometimes neither sutures alone nor conventional application of membranes will be able to completely seal the perforation. Overzealous traction on the sutures might lead to more tears and deteriorating the condition. Also, if not stabilized, a membrane has the tendency to shift upward or medially when placed on the convexity of the junction of the sinus wall and the nasal wall.

One approach in this scenario is to use sutures to reduce the size of the perforation and then use a stiff bioabsorbable membrane leaning on the membrane and remaining sutures. These sutures will now be serving as struts coursing from the membrane toward the lateral wall preventing the upward movement of the membrane.

At times suturing a fragile membrane is not possible or even with sutures the width of the remaining gap remains large, making it difficult to use a stable membrane at this location. In this case, one way is to use a larger size membrane (20 × 30 mm or 40 × 30 mm) and leave a portion of the membrane outside the access window and use tag screws to fixate the membrane.

2.3.5 Perforations with a Diameter Larger than 10 mm

With perforations of this size, sufficient intact membrane on the periphery of the perforation is most probably not at hand regardless of the location of the tear. The chances for displacement of graft material increase leading to inadequate bone formation, infection, or obstruction. In this situation the clinician might decide to stop the procedure and postpone the treatment to 6–9 months later. There are several approaches, however, which can be used to continue the procedure.

One approach is known as the “Loma Linda pouch” technique [20]. In this technique a collagen membrane of adequate size (mostly larger than 40 × 30 mm) is inserted into the maxillary sinus. The membrane should be large enough to extend on crestal and lateral sinus walls and cover the perforated membrane while a portion of it remains outside the lateral window osteotomy. The graft material is then introduced from the window. The resorbable membrane surrounds the particulate the graft material from all sides like a pouch that keeps the graft isolated from the maxillary sinus. The edges of the resorbable membrane extending outside the window can be folded on themselves and seal the window. Alternatively, the membrane can

be fixated by tag screws placed on the upper and lower borders of the lateral window and a new membrane can be placed on the window covering the osteotomy. Care is taken to achieve primary closure by suturing the soft tissue flaps.

Another approach used by the author is using a pedicled buccal fat pad (BFP) graft to create a roof in cases where the sinus membrane is not repairable [19]. The buccal fat can be approached via a 1.5–2 cm horizontal periosteal incision lateral to the zygomatico-maxillary buttress extending backward above the maxillary second molar. Blunt dissection through the buccinators and loose surrounding fascia allows the BFP to herniate into the mouth. The body of the BFP and its buccal extension should be gently mobilized with care being taken not to disrupt BFP's delicate capsule and its internal vasculature and to preserve as wide a base as possible. Placing pressure on the cheek might help to better introduce the fat into the mouth. Once the fat pad is dissected from its surroundings, it can be grasped with a vascular forceps and gently pulled toward the defect. Repetitive motions of gentle pulling, opening the forceps and grasping the fat pad at a place closer to its base ensures a safe method to prepare a pedicled fat graft with proper size and intact blood supply.

Next, one or two holes should be prepared in the palatal wall of the sinus using a fissure bur (702) approximately 1 cm above the sinus floor. The bur should drill through the palatal mucosa and the palatal wall with a safe distance from the greater palatine bundle. Then, a vicryl 4–0 suture with an 18-gauge needle is introduced to the sinus cavity through the hole prepared on the palatal side and grasped with a forceps from the lateral window osteotomy. The needle then takes two bites of the prepared buccal fat pad at a reasonable distance from each other and is guided back toward the palatal wall through the sinus. Once the needle exits the palatal wall it can be tied over the palatal mucosa pulling the BFP with it and creating a new roof for the sinus. Creating two separate palatal holes better ensures a durable knot and is recommended by the author. One modification to this technique which is tremendously helpful when an Oro-antral fistula has been created with limited soft tissue for primary closure, is to prepare a bilobular flap. One lobule is pulled with suture toward the palatal sinus wall and the other lobule can be used to cover the lateral window osteotomy. If BFP is not being used to cover the lateral window osteotomy, a resorbable membrane should be used over the lateral window after the particulate graft has been introduced to the sinus cavity under the new BFP roof (Fig. 15).

2.4 Postoperative Care

All procedures carried out on the maxillary sinus require prophylaxis and postoperative antibiotic therapy and treatment of a membrane perforation is not an exception.

Patients should be prescribed Amoxicillin (875 mg) with clavulanic acid (125 mg) twice per day by mouth for 7 days. For those allergic to penicillin, Clarithromycin 250 mg twice per day and metronidazole 500 mg three times per day for 7 days is recommended. Maintaining excellent oral hygiene is a must. So Patients should be told to brush and rinse from the day after surgery without disrupting the sutured areas and use chlorhexidine 0.12% mouthwash 3 times a day

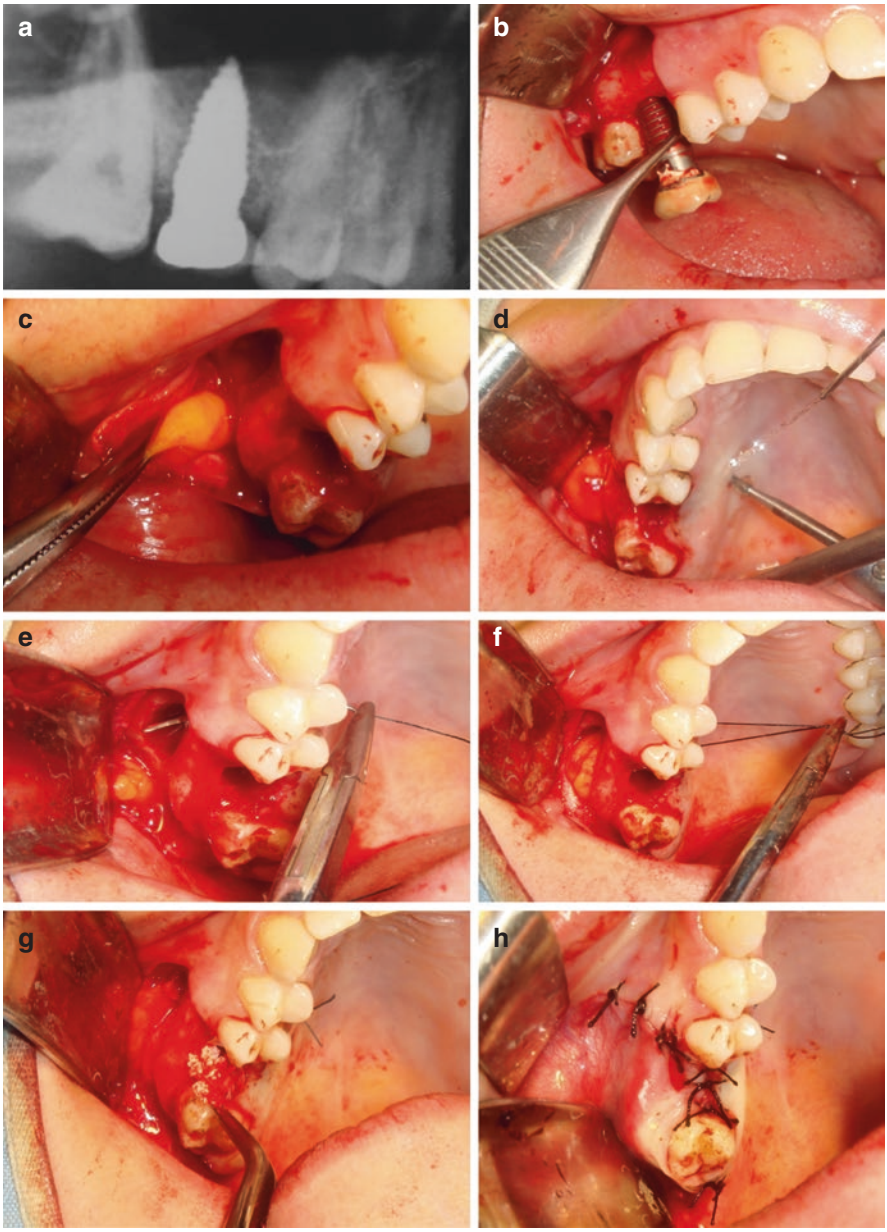


Fig. 15 Failed right upper first molar implant needs to be removed. The main challenge is to debride the infected tissues and prevent formation of an Oro-antral fistula (**a**). The lateral sinus wall is approached by elevating a mucoperisoteal flap and the implant is removed (**b**). The buccal fat is approached by incising the periosteum at the base of the elevated flap and bluntly dissecting through the tissues until the capsule of the buccal fat pad is exposed (**c**). Two holes are prepared transpalatally in the medial sinus wall by a small fissure bur (**d**). A suture is introduced to the antrum via one of the holes and bites the bulk of the buccal fat in two regions and finally exits the sinus by the other palatal hole. By tying the knot the buccal fat is pulled toward the palate and forms a ceiling for the sinus cavity (**d**–**f**). Graft material is placed inside the sinus, below the buccal fat and in the socket and the flap is closed (**h**)

for 2 weeks. The postoperative pain usually subsides with Ibuprofen 400 mg or other NSAIDs every 6 hours. As with all surgeries patient should be instructed to take painkillers before the effect of local anesthetics begin to wear off. In the first 48 h, oozing from the nasal passage close to the surgical site is to be expected as the clot formed in the sinus might eventually exit the sinus from the ostium; therefore patients should be told to keep a head-elevated posture at least for the first 24 h and use icepacks on the skin near the surgical site. Very rarely and probably in patients with an undiscovered blood pressure or coagulation anomaly, bleeding from a nasal passage after sinus surgery might warrant an office visit. In this case, the patient's vital signs should be checked, and a blood-cell count and PT/PTT/INR check should be carried out. A tampon of antibiotic soaked mesh kept in for 24–48 h will almost always resolve the nose bleed, but usually comforting the patient in knowing the condition is transient and natural is usually the only necessary intervention.

All patients should be prescribed phenylephrine 0.25% nasal drop and decongestant antihistamines for at least a week to keep the nasal passages and the ostium unobstructed. The patient should be advised not to engage in heavy exertion and smoking for at least a week and avoid activities which increase the pressure inside the sinus, such as sneezing with a closed mouth or blowing in an obstructed nose for at least 10 days.

2.4.1 Intraoperative Bleeding

Bleeding during any step of the sinus elevation surgery can, at the very least, disturb the visibility of the surgical field. At times the bleeding can be pulsating and stressful to manage for the novice practitioner. Although most cases of intraoperative bleeding in sinus surgery are self-limiting, prevention, and swift management can reduce postoperative patient discomfort and enhance the precision of the surgery.

As described by Solar et al. in 1999, branches of the posterior superior alveolar (PSA) artery course through the soft and hard tissue of the lateral sinus wall. These branches anastomose with branches from the infra-orbital artery and create a double arterial arcade responsible for the lateral sinus wall blood supply [21]. During surgery, vertical releasing incisions can disrupt branches existing in the soft tissue, while a lateral window osteotomy might sever the intraosseous branches. The diameter of the arteries supplying the lateral antrum wall is mostly below 1 mm but can be as wide as 2–3 mm in almost 4% of the cases.

2.5 Prevention

Intraosseous branches of the PSA artery can often be detected in cross-sectional images of the patient's pre-op CBCT. If the artery runs near the sinus floor, this allows for a lateral window preparation which sits completely above the artery and hence, disrupting it can be avoided (Fig. 16). On the other hand, sometimes the cephalic position of the artery on the CBCT allows the surgeon to avoid the artery by limiting the cephalic extension of the lateral window osteotomy. Although all must be done to lessen the morbidity to the patient during surgery, it is not advisable

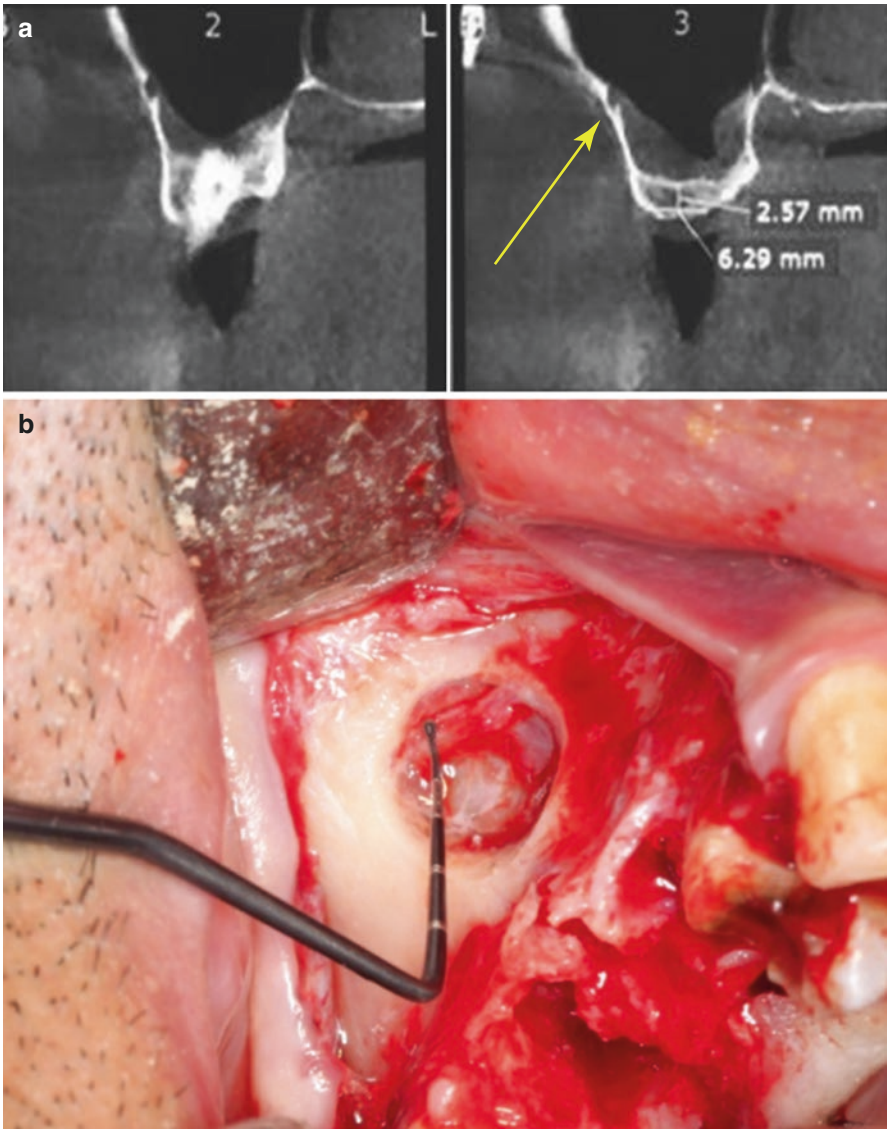


Fig. 16 PSA artery detected in the pre-op CBCT (**a**). If the artery courses at a reasonable distance above the sinus floor, the lateral window is prepared inferior to the artery and the artery is preserved throughout the drilling (**b**)

to settle for a mediocre lateral window preparation placed far from the sinus floor just to prevent a bleeding that can be managed by other means. A lateral window prepared too cephalically might increase the risk of membrane perforation near the sinus floor, a more difficult complication to manage with potentially worse consequences.

Whether the PSA artery branch can be avoided by altering the lateral window preparation or not, the surgeon had better use instruments which distinguish between hard and soft tissue and favor keeping nerves and vasculature in bony sites intact. Piezoelectric surgery is the first choice for this purpose [22] and diamond burs, such as those designed in the Dentium DASK system, allows the surgeon to work more conservatively around the artery.

Even with the preventive measures discussed above, bleeding during lateral window osteotomy might occur and cutting soft tissue branches of the PSA artery situated at the vicinity of the surgical site is sometime inevitable. To ensure efficient soft tissue hemostasis, the local anesthetic injection should contain a vasoconstrictor agent, such as epinephrine 1/100,000 or 1/50,000 (Preferably the latter) if not rendered contraindicated by the patient's systemic conditions, and should be administered at least 7–10 min before making the incision. Injections right before the incision or those applied after the bleeding has started are of little value.

2.6 Management

Managing intraoperative bleeding successfully in sinus surgery is no different from bleeding in other regions and procedures. If the patient's coagulation mechanisms are not flawed, the bleeding will probably self-limit within minutes or with minor help from the surgeon.

Most of the time if the bleeding is not pulsating the surgeon will not need to halt the procedure. Instead, a high power suction tip can be placed near the source of bleeding by an assistant to keep the surgical field free of blood. The surgeon will then go on to complete the procedure, by which time the bleeding has probably already stopped or the bleeding can now be dealt with.

If the surgeon decides to deal with the bleeding before continuing the procedure, the source of bleeding should first be identified. Ruptured branches in the soft tissue can easily be occluded by applying pressure, usually for less than a couple of minutes. During this time it is prudent to check the patient's vital signs to make sure the patient is not hypertensive, as this might cause the continuation of the problem. Alternatively, electrocautery can be used. Nevertheless, cautious is advised when using electrocautery as it might lead to loss of soft tissue and difficulties in tension-free soft tissue closure. Also the safety protocols when using electrocautery must be observed such as connecting to the ground.

If the source of bleeding is from within the bone, the priority is to make sure the Schneiderian membrane is elevated from the vicinity of the ruptured artery so that it is not subject to harm when coagulative measures are being applied. The surgeon must increase the lateral window size to the desired portion and carefully lift the sinus membrane from the bone edges. Yet in the rare case of a pulsating bleeding before the osteotomy is complete, a gauze placed on the site and kept in place by the surgeon will at least resolve the pulsation before the membrane elevation can proceed. Once assured that the membrane will be at no harm, the source of intraosseous bleeding can be clamped and crushed with a fine hemostat. Electrocautery can also

be used on the bone with care taken not to harm the Schneiderian membrane. Alternatively, the heated tip of a small burnisher can be used to cauterize the site most of the times. Applying bone wax on the bone surface can minimize postoperative bleeding and help with hemostasis, but is often unnecessary.

2.6.1 Cysts of the Maxillary Sinus

The maxillary sinus is lined with a pseudostratified ciliated columnar epithelium covering a lamina propria containing seromucinous glands. These structures contribute to forming true or pseudo cystic structures, often only noticed by practitioners in radiographs [23–25].

In the literature, there is no consensus when describing the nomenclature for maxillary sinus cysts. For practical purposes, in this chapter we will classify these cystic structures into two main groups: invasive mucoceles and noninvasive maxillary sinus cysts. Mucocele is a true cyst with epithelium lining usually originating from the obstruction of the sinus ostia which has the capacity to expand and cause destruction in the surrounding bony structures and therefore mandates surgical removal [26]. Mucoceles sometimes arise after a maxillary sinus surgery, such as Caldwell-Luc surgery, in which case they are known as a postoperative maxillary cyst.

The noninvasive maxillary sinus cysts, on the other hand, are mostly asymptomatic and present themselves as sessile dome-shaped, faintly radiopacities in radiographs with intact surrounding boney structure. True noninvasive cysts have an epithelium lining and are an accumulation of mucous due to an obstruction in the salivary glands of the sinus in which case they are called "mucous retention cysts." If these structures lack an epithelium lining, they are called pseudo cysts and are believed to be filled with inflammatory exudate. These well-demarcated dome-shaped structures found randomly in 1.4–35.6% of radiographs have been referred to as both mucous retention cysts and pseudo cysts in the literature, yet mucous retention cysts are believed to be smaller and usually resolve with no treatment. These benign lesions don't necessarily reflect a sino-nasal disease and don't require treatment unless they become symptomatic or risk blocking the sinus ostium (Fig. 17).

If a sinus elevation surgery is planned for a patient with a sinus mucous retention cyst or pseudo cyst, the surgeon needs to have a preoperative analysis about the potential symptoms of a sinus disease and the size of the cyst. Surgeons must remember that once the sinus membrane is elevated, a large enough cyst can block the sinus ostium, so it would be prudent to refer patients whose sinus cavity is filled with large cysts to an ENT specialist for functional endoscopic sinus surgery (FESS). The mean diameter of maxillary sinus cysts, however, is reported to be around 1.56 cm which poses no risk for ostium blockage after sinus elevation surgery in a normal patient.

The standard practice when elevating a sinus membrane underneath a mucous retention cyst is first preparing a usual lateral window osteotomy. Then, the fluid inside the cyst can be drained with a 22 gauge needle into a syringe. Draining a clear yellow fluid ascertains that the cyst is a mucous retention cyst (Fig. 18). This will cause the cyst walls to collapse and give into instruments used for sinus elevation with ease. The small perforation caused by needle entry requires no further

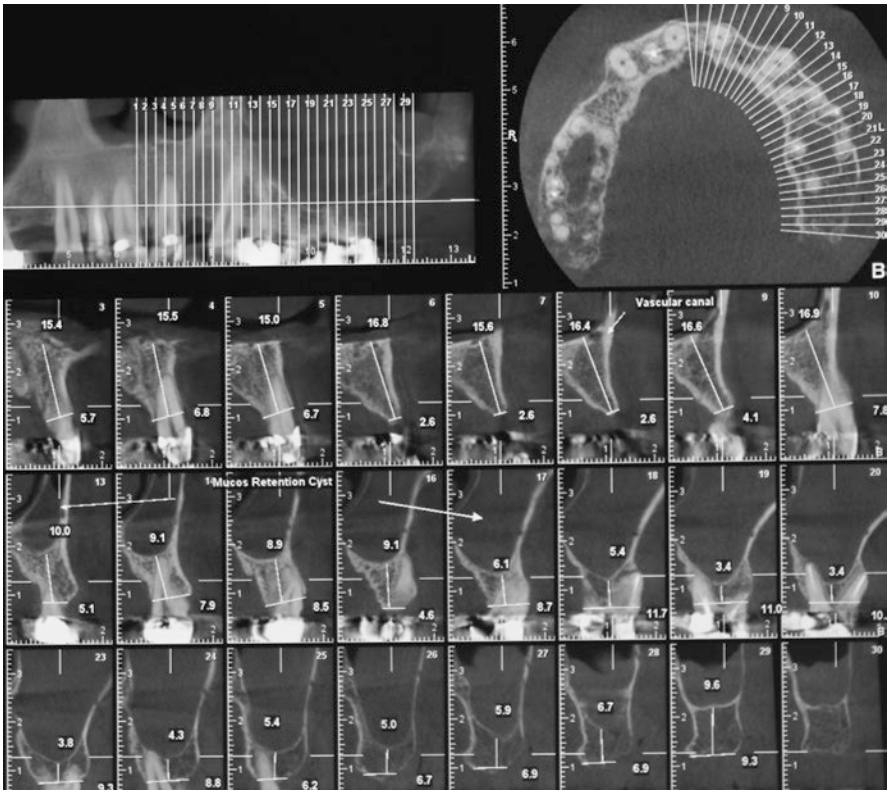


Fig. 17 Maxillary sinus mucous cyst in the left antrum shown in the pre-op CBCT

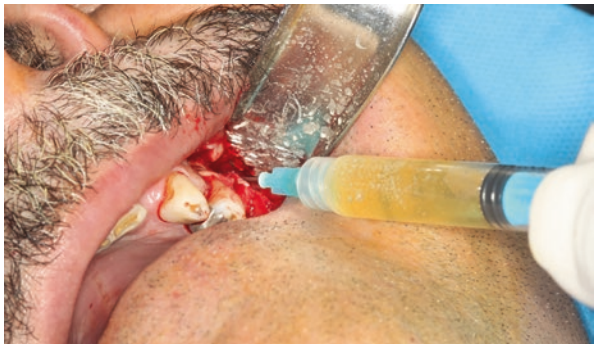


Fig. 18 Muscous drained from a mucous retention cyst after lateral window preparation and prior to sinus elevation

action if elevating the membrane is carried out with precision. Cysts that are managed by this approach usually show no recurrence and the small percentage that recur only do so in a smaller size and with no symptoms; therefore there is no advantage in referring patients with small to medium-sized antral cysts for a FESS procedure [27].

2.7 Postoperative Infection

The surgical site in the sinus elevation surgery is subject to contamination from two separate sources: the oral flora and the sino-nasal flora. However, the rate of post-op infections after sinus grafting has been reported to be less than 5% [28]. The low infection rate might be attributed to the compliant environment of the maxillary sinus or the fact that sinus elevation surgery is a procedure carried out mostly by specialists who are extensively trained in patient evaluation and aseptic techniques. The infection after sinus bone grafting could present itself as either the infection of the graft material isolated from the sinus, or a sinus infection or sinusitis. Each would have different etiologies, symptoms, and treatment protocols, yet in either case they both seem to arise within 3–4 works from the procedure. It is also important to be able to distinguish these symptoms from an emphysema.

2.8 Subcutaneous Emphysema After Sinus Lifting Surgery

Only a few published cases of emphysema after sinus lifting have been reported, but more anecdotal cases do exist. A subcutaneous emphysema is a suddenly arising swelling caused by the passage and entrapment of air beneath cutaneous planes which could be limited or massive in size, and at times threatening important anatomical structures around them by causing pressure. In cases pertaining to sinus surgery, emphysema usually occurs at the first postoperative day, or within the first week at the latest, in patients who have taken for granted the precautions about avoiding activities which create pressure in the sinus. The patient usually reports that the swelling began right after they blew into an obstructed nasal passage. There are times when a membrane perforation goes unnoticed, because it was created during placing the graft material or simply because it was too small to be noticed; therefore the surgeon must place emphasis on the importance of sinus care guidelines to every patient [29].

Of the cardinal signs of infection, patients with emphysema usually only have the swelling which could be limited to the maxillary vestibule or be spread over the paranasal area, but all the other local and systemic signs of infection such as tenderness or warmth would be absent. The crepitus heard and sensed when palpating the swelling is a pathognomonic sign of air entrapment beneath the skin. In a case reported by Farina et al., abrupt swelling had extended to the periorbital regions causing alterations in the patient's vision [30]. If the swelling is limited to the maxillary vestibule, no specific change needs to be made in the post-op care, other than doubling down on the importance of taking postoperative instructions and prescriptions seriously. It is wise to continue prescribing the normal post-op antibiotic regiment until the swelling subsides.

However, If the emphysema has spread to the periorbital regions or intraorally toward the pharynx, the patient should be hospitalized and consulted with other specialists for safety. It would be prudent to prescribe intravenous antibiotics (Penicillin/Cephalosporin) and corticosteroids (Dexamethasone IV 8 mg every 8 h),

the latter being an adjunct to the normal anti-inflammatory post-op regiment, to ensure the swelling does not further expand to other regions. The nasal passage should be kept open by phenylephrine 0.25% in the first week following the surgery. If the course of recovery goes as expected, the emphysema will subside within 10 days.

2.8.1 Infection of the Graft Material

The graft infection usually presents itself as swelling and tenderness in tissues over the lateral window osteotomy. Pus discharge might exist from a fistula away or at the crestal incision and in more severe cases, the surgical wound might be opened creating an Oro-antral fistula. As mentioned earlier, symptoms usually arise in the first 3–4 weeks after surgery.

Without the clinical signs, radiographic changes in the first month are not diagnostic for an infection as the radio-opacity of the different graft materials could be different from one another. Though at the presence of clinical symptoms a radiolucent core surrounded by a radio-opaque halo, which signifies the unaffected graft material around a nidus for infection, is highly suggestive of infection of graft material.

Several factors increase the risk for graft material infection. Membrane perforations can expose the graft to the sino-nasal flora. According to Nolan et al. after retrospective evaluation of more than 350 cases, graft infection is more prevalent in cases in which membrane perforation occurs [17]. If any procedure aimed at horizontal or vertical augmentation of the maxillary alveolar ridge is carried out simultaneously with the sinus surgery, this places greater tension on the soft tissue before closure and might lead to opening of the wound and leaking of saliva into the sinus [31]; therefore, careful planning and meticulous execution should be observed by the surgeon whenever these procedures coincide. Neglecting the aseptic technique during the procedure can be another factor and finally, untreated sources of infection such as periapical or periodontal lesions in teeth adjacent to the site can act as the nidus of infection.

Strategies for prevention revolve around avoiding any of the etiologic factors just mentioned. Prescription of prophylactic antibiotics is also mandated before sinus elevation surgery. Amoxicillin (875 mg) with clavulanic acid (125 mg) twice per day by mouth starting 24 h before surgery is probably the most universally prophylactic regiment prescribed. For patients allergic to Penicillin, a mixture of Clarithromycin 250 mg twice per day and metronidazole 500 mg three times per day by mouth starting 24 h before surgery, can be used.

2.9 Management of Postoperative Graft Infection

Signs and symptoms relating to a post-op infection should be managed as swiftly as possible. The patient should be instructed to contact the surgeon if an increase in swelling, tenderness, erythema, and fever presented itself after 48–72 h. The patient must be visited by the surgeon and not by the office staff and an OPG and periapical

view of the surgical site should be obtained. Once the occurrence of infection is established, it is prudent to carry out the management in two phases.

1. If the signs are only mild to moderate and the patient is not lethargic or febrile, the patient should be asked if he/she has taken the prescribed medication in the previous days. If not, the same postoperative antibiotics can be given, and if yes the surgeon might decide to switch to intramuscular procaine penicillin 800,000 IU every 12 h and oral metronidazole 250 mg every 8 h for at least 5 days based on the severity of the infection. As basic principles to managing infection implies, an accumulation of pus under oral mucosa should be drained with a small incision preferably placed away from the tissues over the lateral window osteotomy or the crest. Also the patient must be strictly advised to rinse with chlorhexidine 0.12–0.2% for 2 weeks and take the oral and nasal drop decongestants regularly as prescribed. If the infection is only located in the soft tissue and superficial layers of the graft material, chances are that the above actions will alleviate the signs and symptoms.
2. If the infection arises with severe signs and alters the systemic condition of the patient, or if the treatment of a mild to moderate infection has failed to improve the situation after a week, the surgeon should not hesitate to open the surgical wound and carry out a thorough debridement of the graft material. Some practitioners advocate partial debridement of the graft and leaving particles which seem unaffected and unchanged in color be. In the author's experience, however, unless the infection has only affected the graft superficially adjacent to the lateral window, the benefits of a complete debridement outweighs its drawbacks. First of all, judging the depth of the infected graft material is easier said than done. Also, a thorough debridement will allow for an inspection of membrane perforations and existence of granulation tissue from the apices of the adjacent teeth in the sinus that have gone unnoticed. Last but not least, a partial debridement does not warrant adequate augmentation of the sinus floor once the infection has alleviated.

Simultaneous bone grafting after the debridement is not contraindicated and is subject to the judgment of the surgeon to decide whether the etiologic factors initiating the infection have been controlled or not. If simultaneous grafting after debriding an infected sinus is planned, the author prefers to rinse the sinus cavity with a mixture of Gentamicin or Tobramycin and metronidazole for at least 2 min before placing the new grafts (Fig. 19).

2.9.1 Postoperative Sinusitis

Acute or chronic sinusitis after sinus bone grafting is not a common finding. In a standard sinus elevation procedure, the graft material stays outside the sinus cavity. It is normal to expect a brief period of increased inflammation of the sinus

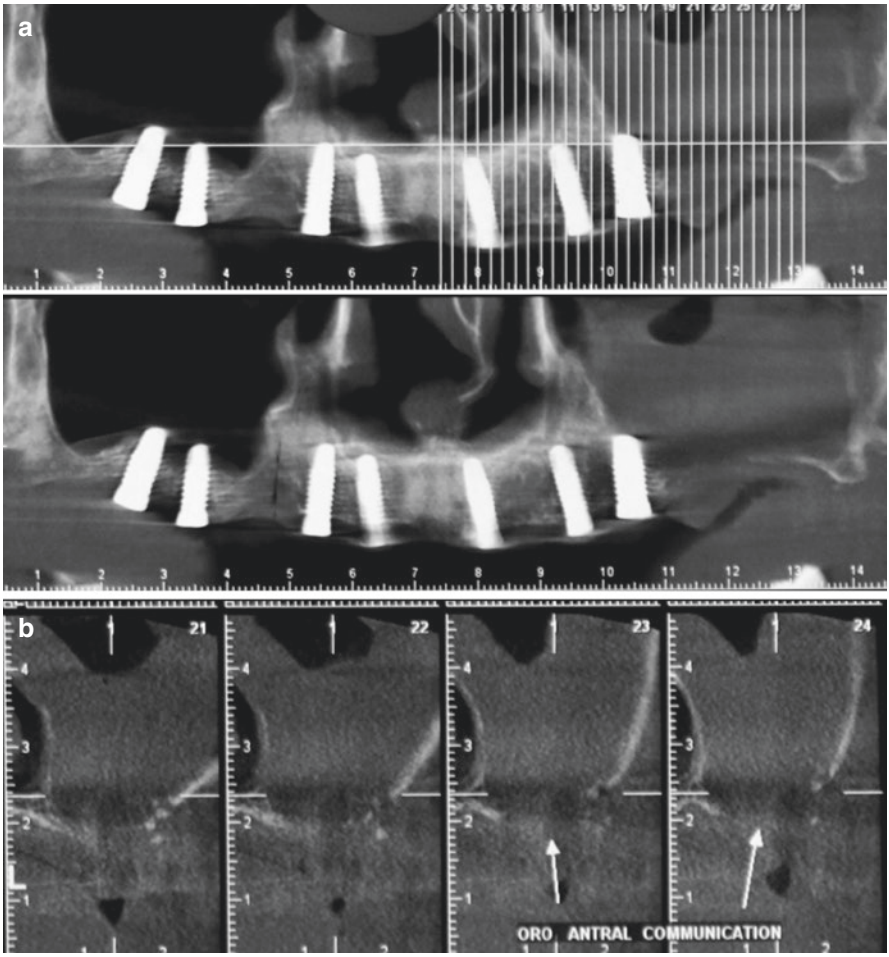


Fig. 19 Case of Oro-antral fistula following the removal of a failed implant placed at the left upper first molar site due to a postoperative infection and sinusitis. Note the opacity of the left antrum in the CBCT (**a**, **b**) and the granulation tissue at the site of implant removal (**c**). The granulation tissue invaginating from the sinus membrane and mucosa was removed and the site was debrided and defistulized. Affected and thinned bone from around the fistula was also removed (**d**, **e**).The buccal fat was approached and pulled toward the defect with a fine hemostat while taking care to preserve the fat pad's capsule (**f**, **g**). Two holes are drilled transpalatally in the medial sinus wall and the buccal fat is pulled inside the sinus cavity via a suture and tied to the medial sinus wall, forming a barrier between the sinus and the oral cavity (**h**–**j**). The buccal fat pedicle is split in half and the outer half will be used to provide coverage for the oral mucosa where the bony defect exists. Graft material is placed inside the sinus cavity and between the pedicled buccal fat lobules (**k**). The outer buccal fat lobule is sutured to the palatal mucosa, completely isolating the graft material and the sinus cavity from the oral mucosa. Final closure is obtained by suturing the mucoperiosteal flap (**l**). Postoperative follow-up after 10 days (**m**)

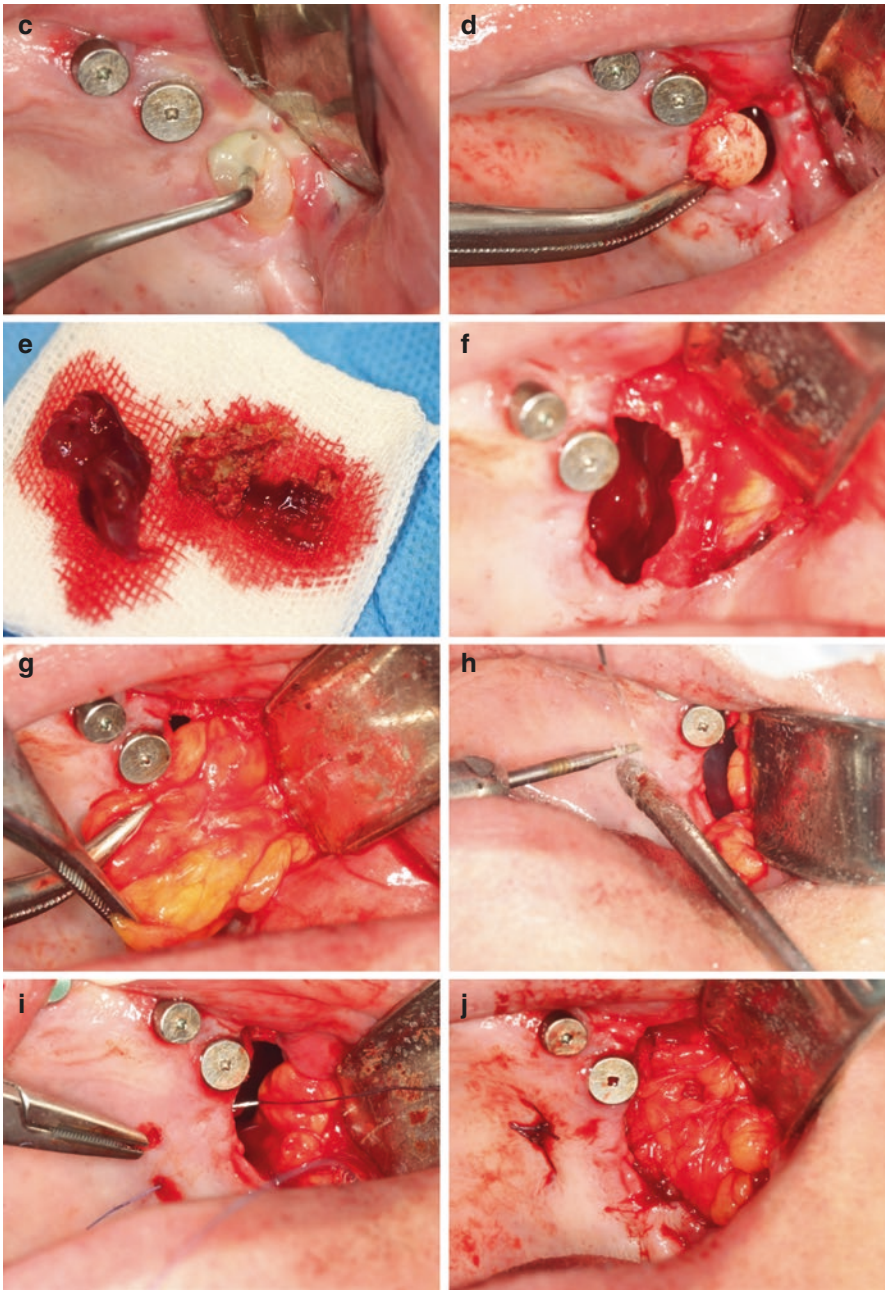


Fig. 19 (continued)

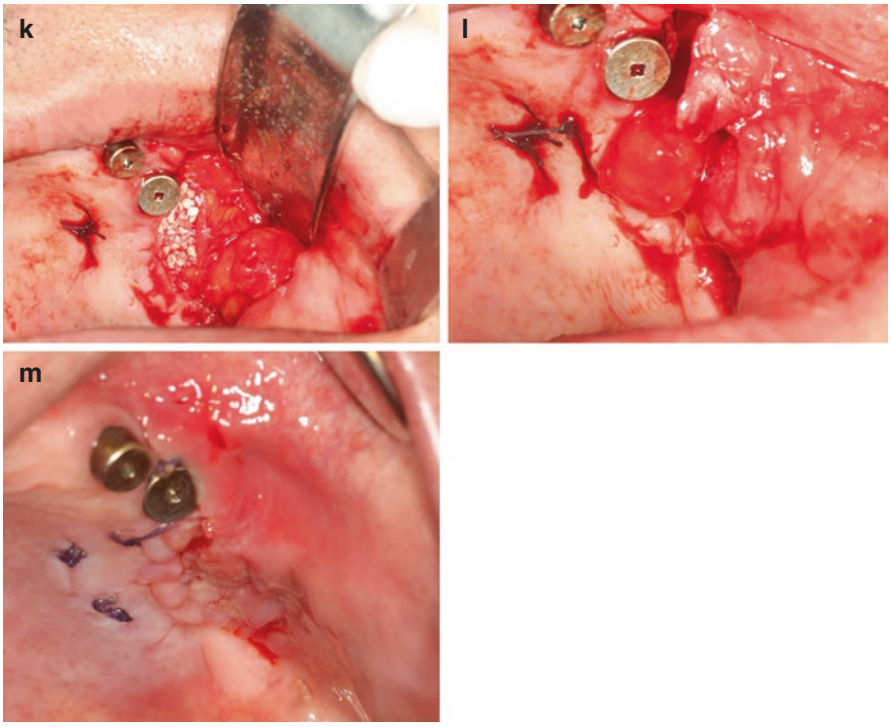


Fig. 19 (continued)

membrane due to the manipulation and inevitable bleeding that occurs. If the inflammation progresses to a point where the sinus ostium is blocked by congestion, or the graft material or infection results in blockage of the ostium, physiological maxillary drainage into the middle meatus will be impeded and predisposes the patient to acute maxillary sinusitis with signs and symptoms including headache, nasal stuffiness, regional pain, post nasal drip, cacosmia, and unilateral nasal discharge alongside systemic alterations such as fever [32].

2.10 Etiology and Prevention

In a report by Manor et al., the most significant factors attributed to postoperative sinusitis after sinus elevation surgery were a history of preoperative sinusitis and sinuses with thick mucosa ($P < 0.0001$) whether the disease is controlled prior to sinus surgery or not [33]. Surprisingly, intraoperative complications, including membrane perforations and bleeding did not statistically increase the risk of postoperative

sinusitis. Therefore, patients with a history of preoperative sinusitis and evidence of thick mucosa in the radiograph need to be warned about the potential risks and must be followed up closely and treated swiftly if signs and symptoms of sinusitis emerge.

One important preventive principle is not to operate on patients with existing signs of sino-nasal diseases. Pignataro and Mantovani believe that the most important preventive principle to avoid postoperative sinusitis is to have an ear, nose, and throat (ENT) specialist evaluate every patient who is a candidate for sinus elevation surgery first [34]. They also describe three steps by which collaborating with an ENT specialist will prevent a postoperative sinusitis:

1. Excluding naso-sinusal diseases indicating a contraindication for sinus surgery, also referred to as irreversible pathologic findings (such as cystic fibrosis, certain immune suppression conditions, scarring due to radiotherapy, etc.).
2. Managing reversible sinus conditions such as acute or chronic rhinosinusitis via medication or functional endoscopic sinus surgery (FESS). Sinus elevation surgery can proceed 3–4 weeks after the endoscopic surgery.
3. Prompt diagnosis and appropriate treatment of postoperative complications.

Although in clinical practice, referring all patients for an ENT work up might not be necessary, this paper highlights the importance of proper patient evaluation and selection and underscores the importance of collaborating with ENT specialist to diagnose and treat sino-nasal diseases. The authors believe all cases of chronic rhinosinusitis (lasting more than 12 weeks), a history of previous sinus trauma or surgery, and with evident radiographic findings suggestive of pathology other than small to moderate size mucous retention cysts should strictly be referred to an ENT specialist before sinus lifting.

In the case of acute sinusitis although a great majority of cases are self-limiting, there is still advantage in referring the patient to an ENT specialist. Unnecessary antibiotic treatment by an inexperienced practitioner will exert cost and harm to the patient and the society. Also, ineffective management might lead to direr consequences such as pansinusitis, or a more chronic form of the disease. If the condition is of viral origin, signs and symptoms will subside with only symptomatic relief provided by decongestants and topical intranasal steroids or no treatment at all in mostly 10–14 days and sinus surgery can be carried out afterwards. If the signs don't resolve within 10 days or worsen after a week, the condition is probably of bacterial origin and antibiotic therapy is indicated. The first line of antibiotic therapy is still amoxicillin with clavulanic acid [32].

2.11 Management

First and foremost, all patients under sinus elevation surgery should be prescribed with decongestants and anti-inflammatories to reduce the risk of antral ostium blockage. It is also helpful to prescribe phenylephrine 0.25% nasal drop to keep the nasal passages open and help with postoperative epistaxis just in case. The mild

inflammatory reaction in the sinus as an inevitable response to the surgery is easily managed with these medications, provided the patient also follows sinus care guidelines seriously.

If the signs and symptoms are mild and the graft material is not spread into the sinus cavity, symptomatic treatment and routine postoperative medication including antibiotics might help relieve the condition. If the condition is severe from the beginning, shows no improvement after a week or deteriorates with time, an intraoral approach for debriding the graft material, removing simultaneously placed implants and lavaging the sinus should be planned as quickly as possible [10].

If the signs and symptoms exist with graft material being displaced inside the sinus, surgical debridement of the sinus and graft material should be planned by collaboration with an ENT specialist. Usually both the intraoral approach and nasal endoscopy is required to ensure thorough debridement of the sinus, removing implants if necessary and guaranteeing sino-nasal patency [35]. Transnasal endoscopy also offers the advantage of obtaining a sample from sinus secretions to perform antibiogram testing. Intra oral samples are usually less valid as they become contaminated with oral flora easily.

2.11.1 Transcrestal Technique

If the remaining alveolar bone height underneath the sinus is 5–6 mm with adequate width, the clinician has three choices for placing a dental implant:

1. Placing a short implant with 6 mm of height and 5 mm width if the residual bone thickness allows at least 1 mm of bone around all implant surfaces. Though short implants have shown triumphant results in the short term, it might be still early to judge their long-term success. Also, at the posterior maxilla much preparation and careful execution should go into ensuring these short implants are placed with as high primary stability and bone to implant contact (BIC) area as possible.
2. Sinus elevation surgery with a lateral window osteotomy approach. Not only this approach might be unnecessary, but also since the lower margin of the window should be placed at least 2–3 mm above the sinus floor, the access requires elevating a longer flap and undermining more soft tissues and it, therefore, can be more difficult than transcrestal sinus elevation. There are instances when the surgeon might choose this approach: when the patient has a history of benign paroxysmal positional vertigo (BPPV) and is in greater risk of discomfort if osteotomes are used, or when a membrane rupture has occurred in the transcrestal approach that cannot be repaired otherwise.
3. Transcrestal sinus floor elevation with the sequential use of drills to the depth of 1 mm below the sinus floor and fracturing the sinus floor with the membrane attached to it with the controlled forced of an osteotome. This is the preferred approach since it provides the chance of placing an implant with 8.5–10 mm of height and it does so with less morbidity to the patient. After the sinus floor is elevated, placing graft material beneath the membrane is possible but not necessary for bone formation.

Like other surgical approaches, the transcrestal sinus elevation can lead to certain complications. Postoperative infection and sinusitis will not be alluded to in this segment as they were already discussed in the previous topic.

Membrane Perforation

As with the lateral window osteotomy technique, membrane perforation is the most common complication following transcrestal sinus elevation. Perforation might happen at any of the sequential steps, including drilling, osteotomy of the sinus floor, placement of graft, and implantation. The biggest difference when comparing membrane perforation in this approach and the lateral window approach is that both diagnosing and managing a torn membrane is more difficult in the transcrestal approach due to less visibility and poorer access.

Several factors may increase the risk for membrane perforation in the transcrestal approach:

1. Membrane thickness below 0.5 mm or more than 3 mm leads to more instances of perforation [36].
2. As the extent to which the membrane is elevated increases, the risk for perforation also rises. Therefore we recommend that for procedures needing more than 3–4 mm of elevation, a lateral window osteotomy should be used.
3. The more the difference between the diameter of the final osteotome and the width of the sinus floor, the higher the risk for membrane rupture. That is why the Schneiderian membrane can be elevated with greater ease and safety in cases where the sinus cavity is narrower [37].
4. Presence of anatomical variations, specially septas or adjacent sinus walls increase the risk for membrane perforation.
5. The surgeon's experience, dexterity and familiarity with the instruments being used is key to avoid the incidence of membrane tearing. Even seasoned specialists have limited control over the magnitude and direction of the force that a mallet and osteotome exert on the membrane through the sinus floor.

2.12 Prevention

Careful patient selection and evaluation is the basis to preventing all surgical complications. Cone-beam CT scan can help surgeons meticulously choose drilling depths and the depth at which the osteotome should be used. It is generally best if drilling is carried out one size smaller than the final size of the implant and 1 mm shorter than the sinus floor. To make sure the right depth has been reached, a periapical radiograph with a drill or curette placed in the osteotomy is invaluable. Then an osteotome, closely yet passively fitting the osteotomy, should be placed beneath the sinus floor. The pressure exerted by the mallet should be the smallest amount required to infracture the sinus floor without entering the sinus cavity by more than 1 mm. CBCT can also be used to assess the existence of septas, evaluate sinus health, and estimate membrane thickness.

Several systems have been designed to make transcrestal sinus elevation safer. Piezoelectric instruments selectively work on bone and keep soft tissues out of harm. Different companies have come up with a sequence of soft diamond drills which can safely drill the bone out with precise control over their depth of intrusion via stoppers. Recent solutions include hydraulic and hydrodynamic ultrasound systems which can lift the Schneiderian membrane by exerting equally distributed force under all parts of the membrane and therefore reducing the risk of rupture [38]. It is important to know that none of the above mentioned systems completely eliminate the risk of membrane perforation and the surgeon should not make up for haphazard preparation and execution with modern armamentarium.

2.13 Management

The first step is to diagnose whether a membrane tear has occurred and estimate its severity. Several methods might help make the diagnosis such as direct visualization, the Valsalva maneuver, witnessing abrupt bleeding from the osteotomy, the nose blow test, or probing the osteotomy with a blunt instrument. None of these methods, however, are devoid of disadvantages. Visualization might be extremely hard due to the nature of the technique and the Valsalva test can yield false negative results and the other methods might turn a small perforation to a big one if not used with care. The best way to ascertain whether membrane perforation has happened is by endoscopy [39].

When the existence of a perforation is suspected based on any of the aforementioned diagnostic techniques, It is best to place a collagen membrane or a platelet-rich fibrin plug made by centrifuging a sample of the patient's whole blood below the membrane and avoid using particulate bone material [40].

If an implant is going to be inserted simultaneously after the attempted perforation repair, it had better not enter the sinus cavity more than 2 mm. At this depth, if the membrane is cushioned by the PRF plug or the membrane, we can expect bone formation around the apex of the implant. If not, at this depth we can expect the sinus membrane to cover the implant once it is healed but no bone will be generated around the apical 1–2 mm of the implant.

In the case that more augmentation in the sinus floor is required, two options remain: First, the surgeon might decide to postpone placing of the implant or the entire procedure. Once the PRF plug or the collagen membrane has been inserted, the drilled osteotomy size will be filled with graft material to a depth below the sinus floor. The crestal osteotomy should also be covered with a membrane to lessen the risk for the formation of an Oro-antral fistula. Follow-up for a new sinus elevation surgery or implantation will be postponed to approximately 4–5 months. The second option is to try a lateral window osteotomy to visualize the membrane perforation and repair it.

2.13.1 Benign Paroxysmal Positional Vertigo

As the most prevalent form of vertigo in the population, the etiology of benign paroxysmal positional vertigo (BPPV) is believed to be caused by dislodgment of

inorganic particles (otoliths) from the utricular macula of the ear vestibule [41]. These otoliths could float in any of the semicircular canals stimulating the free nerve endings in these structures which can cause vertigo and imbalance. Symptoms including dizziness, short-term recurrent vertigo and intense nystagmus usually present themselves when the patient makes a sudden change in his/her position, as the sudden placing of the patient in the supine position in the diagnostic dix-hallpike maneuver triggers the symptoms.

The exact etiology for the dislodgment of otoliths are unknown, yet various reports support the influencing role of head trauma. Percussive and vibrational forces to the head produced as a form of dental treatment are also considered a causative factor with more emphasis placed on percussion. Another contributing factor is the position and extension of the patient's head [42]. The supine position and hyper extension of the neck lends to entry of dislodged otoliths into the posterior semicircular canal. Collectively, these factors make osteotome mediated transcrestal sinus elevation a procedure with a higher risk for BPPV in comparison to all other dental procedures.

The resulting vertigo, however short in every episode, could be debilitating. Patients might experience disorientation during and shortly after each episode and demand a treatment [43]. Multiple surveys attest to the fact that at the absence of symptoms of BPPV, malleting osteotomes is, at the very least, an undesirable experience for the patient, specifically if the patients have not been prepared for it in advance.

2.14 Prevention

With the help of proper planning and new drill-based, hydrodynamic, and ultrasound systems introduced for transcrestal sinus elevation, the need for tapping an osteotome can be minimized. Nevertheless, preparing the patient for the procedure and explaining every step in advance is of paramount importance even if the surgeon believes the minor tapping required would be innocuous to the patient.

It is important to stabilize the patient's head while malleting. The assistant can do so by placing a hand gently on the patient's forehead without exerting too much pressure in any direction. Talking to the patient before and during the procedure can help the patient feel more at ease and comply.

2.15 Management

Symptoms might be self-limiting and usually resolve within 1 month. However, most patients demand a treatment due to the debilitating nature of vertigo episodes. This condition can be effectively managed by an experienced ENT specialist using the "Eplay maneuver" which consists of a sequence of patient positioning that helps guide the dislodged otoliths out of the semicircular canals [44].

Talaat et al. showed that development and recurrence of BPPV can be attributed to severe vitamin D deficiency and correcting hydroxyvitamin D3 serum levels can

significantly decrease the recurrence of BPPV [45]. Betahistine dihydrochloride is another medication that seems to facilitate the recovery of the vestibular system via improving the blood flow in the middle ear after successfully administrating the Eplay maneuver [46].

2.15.1 Displacement of Implant in the Maxillary Sinus

This rare complication could happen at any stage during the implant treatment. An implant displaced in the maxillary sinus can migrate beyond the antrum to other sinus cavities [47]. It most commonly happens during the insertion of an implant in a severely atrophied maxilla with type IV bone, yet it could also happen during the healing stage or after the final restoration is cemented on the abutment. It is believed that a combination of factors including lack of primary stability, unsuccessful osseointegration, and tearing of the Schneiderian membrane lead to migration of the implant into the sinus after the initial surgery. Migration of the implant into the antrum can block the ostium, cause sinusitis and create an Oro-antral fistula [48].

2.16 Prevention

When the remaining bone height at the posterior maxilla is less than 3–4 mm, simultaneous implantation with sinus elevation surgery increases the risk for lack of osseointegration and displacement of the implant into the antrum. Also when operating on type IV bone in the posterior maxilla, it is recommended to underprepare the implantation site by one drill size. Using countersink drills in the implantation kit should be avoided when placing implants in the maxilla. These measures will allow the surgeon to achieve higher insertion torques and better primary stability.

When using short implants in particular, it is strongly advised not to rely merely on the CBCT measurements of bone height. It is always helpful to check the drilling depth with a blunt gauge to ensure an apical stop exists at the apex of the drilling or determine whether cautious drilling of the sinus floor has been done at the planned depth.

There are times in which due to inadequate bone to implant contact in fresh socket implantation, iatrogenic factors, or the osteoporotic quality of the bone in the posterior maxilla, the insertion torque does not exceed beyond 15 Ncm. In these cases, if the sinus floor is drilled and an apical stop is absent at the apex of the drilling, excessive forces of loading the cover screw or healing abutment might be able to push and screw forward toward the sinus cavity. Thus, the clinician must have this in mind in such cases.

2.17 Management

Removing the displaced implant during the insertion surgery is relatively easy after sinus lifting with the lateral window approach. If displacement occurs after a closed sinus lift is planned, creating a lateral window to access the sinus will be necessary.

If the implant cannot be readily located after insertion or in the case of delayed migration, the exact position of the implant should be identified by CBCT [47–49].

Some practitioners have suggested no treatment for displaced implants with no signs and symptoms migrating to areas adjacent and below the orbit, but Chiapasko et al. believe that all implants displaced into the sinus should be removed to prevent potential complications [50].

The three main techniques for removing an implant displaced into the antrum are the Caldwell-Luc approach, trans-oral endoscopy via the canine fossae and transnasal functional endoscopy surgery (FESS). When migration of implants or roots has blocked the sinus ostium and the patency of the antrum is compromised, a combination of intraoral and FESS approaches probably works best.

When access to the sinus is obtained through the Caldwell approach, a mucoperiosteal flap extending well beyond the Oro-antral fistula (if present) with vertical incisions is raised. Next, a lateral window can be drilled out of the sinus lateral wall or can stay attached to the Schneiderian membrane. The sinus membrane must be incised if not already torn to allow the surgeon to access the sinus cavity. The displaced implant can be removed by irrigating and suctioning the sinus or by just using fine suction tips alone. Alternatively, fine sinus lift instruments can be used meticulously to tease out the implant from its location.

The functional endoscopic sinus surgery should be carried out under general anesthesia by an ENT specialist and is indicated when the ostium of the sinus is blocked or when the implant has migrated to other paranasal sinuses such as the ethmoid or the sphenoid sinus [51].

If the conditions allow, the authors believe simultaneous repair of the Schneiderian membrane and sinus grafting and even implantation can be carried in the same session the displaced implant is removed from the sinus. Existence of signs and symptoms of acute sinusitis is a contraindication for simultaneous grafting procedures (Fig. 20).

3 Graft-Free Procedures to Rehabilitate the Atrophic Maxilla

3.1 Zygomatic Implants

Introduced first by Branemark in the late 1980s, the zygomatic implants aim to utilize the bone anchorage available in the zygomatic basal bone for occlusal rehabilitation in patients with basal maxillary bone defects, due to maxillary resection surgeries, or in patients with severe atrophy of maxilla [52]. Zygomatic implants can provide a treatment which eliminates the need for grafting and potentiates immediate loading (Fig. 21).

The original surgical technique proposed by Branemark meant for the trajectory of the implant to start from the palatal bone in the second premolar or first molar region, maintain an intra-sinus path and end in the zygomatic basal bone inferior to the lateral orbital rim and medial to the zygomatic arch. If two zygomatic implants are supposed to be placed, the anterior implant will enter the bone at the lateral

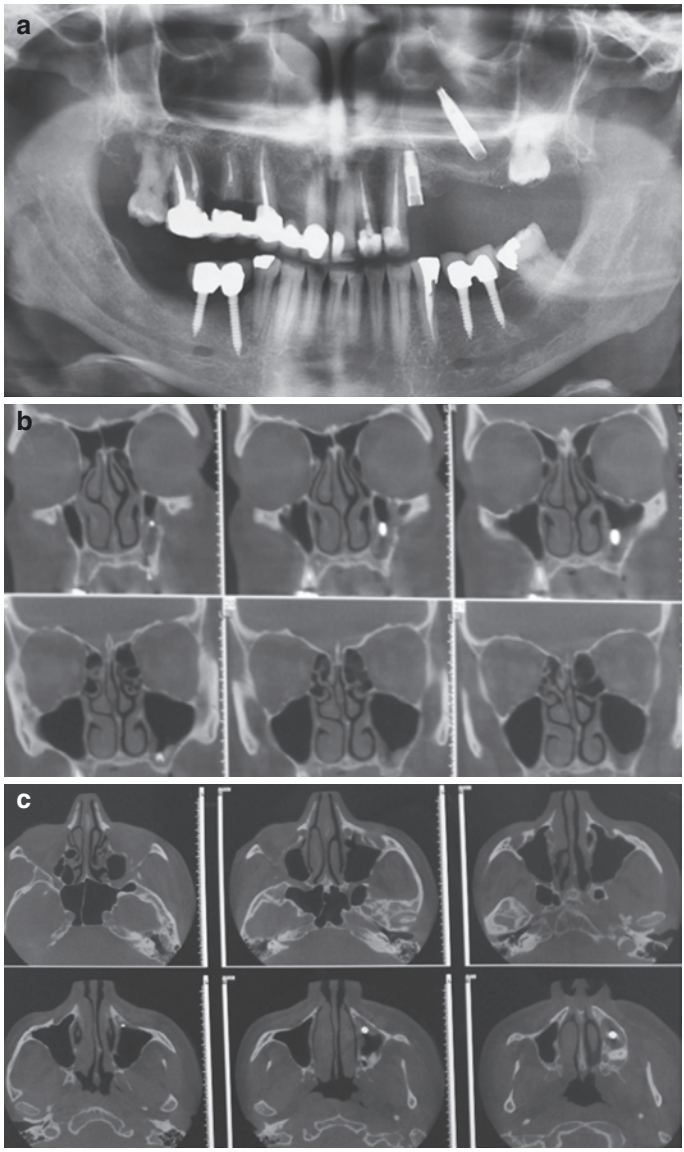
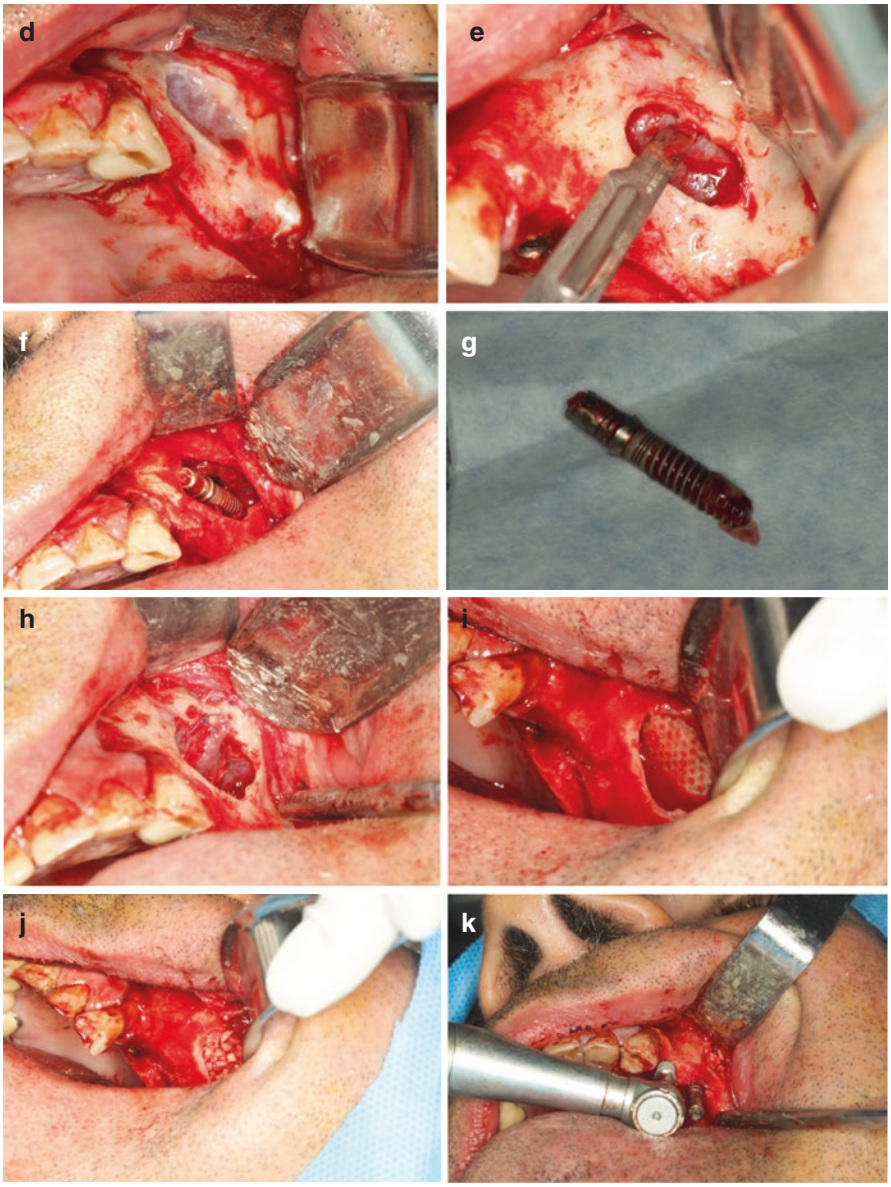


Fig. 20 OPG (**a**), Coronal and axial CT scans (**b**, **c**) showing the position of the displaced implant inside the maxillary sinus. Note that the opacity around the implant, suggestive of an infectious reaction. The implant is located below the level of the maxillary arches, so it is resting on the sinus floor near the maxillary molar area. Lateral bone window is drilled out adjacent to the location of the implant determined by the CT scan (**d**). The Schneiderian membrane is incised. This is preferred to drilling into the Schneiderian membrane as incising the membrane will keep sound remnants of the membrane around the incision which are amenable to repair (**e**). implant exposed after extending the window and incising through the membrane (**f**). The displaced implant removed (**g**). lSchneiderian membrane sutured to the lateral sinus wall with 4–0 vicryl sutures (**h**). A bioresorbable collagen membrane is placed below the membrane covering the reparied segment (**i**). Alloplastic bone material is placed in the sinus below the membrane (**j**). Dental implants are placed in the same session (**k**). Post-op OPG (**l**)



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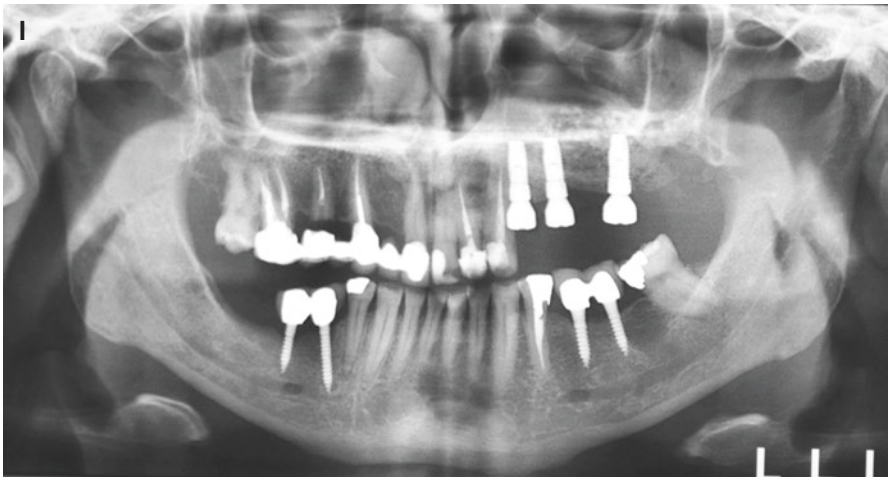

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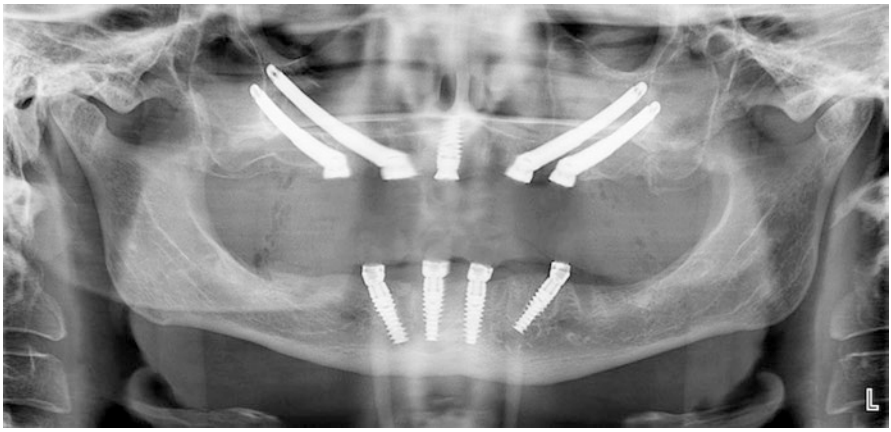

Fig. 21 Occlusal rehabilitation of the atrophic maxilla with four zygomatic implants provides a graftless alternative with adequate anterior-posterior spread. The conventional implant inserted near the maxillary midline helps with load management and maintaining the alveolar bone in the premaxilla

incisor or canine. As a part of the surgery a 5 × 10 mm window in the most distal aspect of the sinus lateral wall is prepared mainly to detach the membrane, without necessarily keeping it intact, from the sinus walls and provide irrigation and suction during drilling. In fact, the zygomatic implant would always disrupt the continuity of the Schneiderian membrane in the original Branemark technique. Aside from the intra-sinus position of the implant which increases the likelihood of postoperative sinusitis, the main disadvantage of the original technique is the palatal emergence of

the prosthetic abutment which can cause biologic, phonetic, and functional complications. The original technique was meant to be carried out in two stages and loading of the implants would be postponed to 6 months later.

In an attempt to lower the complications faced in the original technique, the "zygoma anatomy-guided approach" (ZAGA) is now being practiced by most surgeons. In this approach, the occlusal/alveolar entrance point of the implant is decided based on the optimum position of the prosthetic abutment considering biomechanical and functional principles [53]; Therefore, the intraoral entrance will be at the middle or buccal to the alveolar crest. Aparicio classifies the pathway of implants in the ZAGA approach from the intraoral entrance to its final extraoral apical point in the zygomatic basal bone to five groups [54]:

- Type 0: Intra sinus path (15%).
- Type 1: Intra-extra sinus path (49%).
- Type 2: Extra-Intra sinus path (20.5%).
- Type 3: Extra sinus path (9%).
- Type 4: Extra-maxillary path (6.5%).

In this approach, there is no need for preparing a lateral window and although most implants still disrupt the Schneiderian membrane at some point of their route, postoperative sinus-related complications are lower. The emergence profile of the implant is in a much more desirable position in the ZAGA approach and immediate loading can proceed if the insertion torques are above 30 Ncm.

A recent systematic review by Chrcanovic et al. shows the cumulative survival rate of zygomatic implant to be above 95% after 12 years [55]. Patients' level of satisfaction of zygomatic implants is similar to conventional implants when surveyed [56, 57]. Nevertheless, the learning curve associated with the zygomatic implants and the overall unfamiliarity of surgeons with the armamentarium and the essence of placing zygomatic implants in direct exposure to either sinus mucosa or oral mucosa can lead to complications during or after the surgical procedure which will be alluded to below:

3.1.1 Invasion to Vital Surrounding Structure

A slight miscalculation in the direction of the drilling usually caused by inadequate presurgical planning combined with lack of sufficient surgical access can lead to penetration of drills into the orbit, infra temporal fossa, and the intracerebral regions. Orbital penetration is of greater concern when placing anterior zygomatic implants in a quad-zygoma treatment plan. The penetration of the infratemporal fossa can damage the integrity of the maxillary artery and vein and the pterygoid venous plexus as well as branches of mandibular and facial nerve.

The standard preventive measure is to use 3D radiographic evaluation prior to surgery by CBCT. Surgical guides can be produced by 3D printing to meticulously specify the trajectory of the implant. Intraoperative navigation systems are a recent addition to the surgeon's choices for assuring an uneventful and accurate implantation. As mentioned, the risk of inadvertent drilling of surrounding structures

increases in cases of severe maxillary atrophy, therefore some clinicians advocate implantation in these cases under general anesthesia to maximize surgical access and better manage complications upon their occurrence.

3.1.2 Postoperative Sinusitis

Sinusitis is the most common complication associated with placing zygomatic implants (2–3%). Signs and symptoms of sinusitis mostly arise within the first 6 months after implantation but may also occur years after the procedure. Still no study has been able to reveal whether sinusitis in patients with zygomatic implants is more common than in patients without [58].

The etiology of the postoperative sinusitis is attributed to several factors. The most important factor is a history of sinus diseases prior to surgery. Also it is hypothesized that in a small fraction of patients, the zygomatic implant can itself act as a foreign body inside the sinus causing inflammatory reactions. In this case, removing the implant is mandated for alleviating the symptoms. Another explanation is an unhealed Oro-antral communication as the nidus of sinusitis; failure or lack of osseointegration at the alveolar crest entrance of the implant leaves all the burden of creating a tissue seal to the soft tissue which can be easily broken due to improper hygiene or even iatrogenic cleansing and probing.

Prevention is first and foremost done by a thorough evaluation of the patient's systemic conditions with a focus on a history of sinus diseases. Consultation with the ENT specialist is invaluable in patients with current or previous symptoms of sinusitis or those with radiographic changes suggestive of a sinus pathology. Second, prophylactic and perioperative antibiotics should be prescribed for patients prior to surgery with the same protocol existing for sinus elevation candidates. Prescription of intra-nasal topical decongestants are also highly recommended for the first week after surgery and all patients should be advised not to increase the intra-sinus pressure by sneezing with a closed mouth or forcing air out of an obstructed nose.

Once the signs and symptoms of sinusitis are present, the first line of treatment is prescribing systemic antibiotics and topical decongestants. Amoxicillin with clavulanic acid covers a wider spectrum than amoxicillin alone and is recommended. The authors believe If no improvement in the conditions were noticed after 1 week of antibiotic and decongest therapy, the patient should be referred to an ENT specialist. Prescribing different antibiotics without antibiogram testing might lead to an increase in drug-resistant bacterial colonies. The ENT specialist would also consider the option of endoscopy to ascertain the patency of the sinu-nasal complex and remove polyps that might be obstructing the ostiomeatal complex. Fortunately, if the sinusitis is treated, the Oro-antral communication resulting from it will also close and there would be no need for removing the implant. In recalcitrant cases resistant to antibiotic treatment and endoscopic treatment, the implant should be removed and the Oro-antral communication must be closed surgically. The ZAGA approach is believed to be less associated with postoperative sinusitis compared to the original Branemark technique .

As mentioned earlier, sinusitis after zygomatic implants can arise several years after the procedure. In the rare case that removing the implant was mandated after

osseointegration had been achieved in the apical end of the implant in the zygoma, removing the implant by reverse torque could lead to bone fracture and other complications, therefore cutting the implant from its insertion to the zygomatic bone and removing the rest of the implant is recommended.

3.1.3 Oro-antral Communication

As previously mentioned, lack of osseointegration in the crestal level of the implant can lead to an Oro-antral communication. An infectious process in the maxillary sinus can also find its way outside to the oral cavity from the soft tissue attachments around the zygomatic implants. Upon alleviation of the signs of the sinus disease the Oro-antral communication n will most often close with no need for further correction. When an Oro-antral fistula persists to exist after treatment of other conditions, corrective surgery including elevation of tissue and closure in two (nasal and oral) layers becomes necessary. The surgeon should also consider using pedicle mucoperiosteal or fat grafts for larger defects.

3.1.4 Soft Tissue Dehiscence

In zygomatic implants with an extra-maxillary path (Type 4 according to Aparicio), most of the implant circumference will be directly beneath the oral mucosa. This does not inherently pose a threat to the implant or the soft tissue. Patients with a thin mucosal biotype, however, or in those where the oral mucosa is placed under tension a soft tissue dehiscence over the implant is more likely to happen. Implant exposure might concern the patient, yet seldom poses an esthetic or functional threat to the implant. In fact, if the patient is able to keep the exposed implant threads clean and free of debris no additional treatment is mandated. In case the surgeon decides to cover the implant and close the dehiscence, pedicle mucoperiosteal flaps and/or buccal fat grafts should be considered.

3.1.5 Bulky Palatal Extension of the Prosthesis

In the original surgical technique, the alveolar entrance of the zygomatic implant would be at a point palatal to the crest to ensure an intra-sinus pathway of the implant. The palatal emergence of the implant would give the final prosthesis a bulky palatal extension which is most often a source of discomfort to the patient causing functional and phonetic complications. In the new zygomatic anatomic guidance approach (ZAGA), the alveolar entrance of the implant has a more crestal emergence and does not take up any space in the palate.

Other complications that are not exclusive to zygomatic implants can be listed as periimplantitis, sensory disturbance, bleeding, and hematoma.

3.2 Pterygoid Implants

Another option for rehabilitating the posterior atrophic maxilla without grafting procedures is using 15–20 mm pterygoid implants that are placed at the tuberosity

and course the pyramidal process of the palatal bone and end in the pterygoid plates of the sphenoid bone [59]. Whereas the bone in the tuberosity is mostly cancellous, the bone in the pyramid process of the palatal bone and the pterygoid plates are almost completely cortical. With enough length and proper angulation of 35–55° from the occlusal plane, an implant longer than 15 mm will be able to penetrate the pterygoid plates with an insertion torque higher than 30 Ncm [60]. This will allow for immediate loading of the implant which is an added advantage when compared to grafting procedures. In comparison with zygomatic implants, pterygoid implants can be placed with less difficulty under local anesthesia. However, due to their distal position in the arch, they can only be used if enough number of implants are placed in the more anterior alveolar bone.

The success rate of pterygoid implants has been reported to be above 90%, with most failures occurring before the implant is loaded (Fig. 22). Complications are rare and mostly include loss of implants due to incorrect site preparation and not being able to engage the dense cortical pterygoid plates [61]. To avoid this complication, the surgeon is required to carry out the osteotomy or drilling with enough length and angulation and use implants of correct length as well. If cortical bone is not encountered at a drilling depth of almost 15 mm, the angulation of drilling is probably incorrect. Whenever displacement of the implant into the sinus cavity or other unwanted areas occur, a CBCT can best identify the location of the implant.

Practitioners may be mostly concerned about the risk of bleeding, yet the maxillary artery courses at least 1 cm above the pterygomaxillary suture which is a safe distance from the osteotomy [62]. The source of bleeding at the site is most commonly the pterygoid plexus of veins which can be managed with local measures.

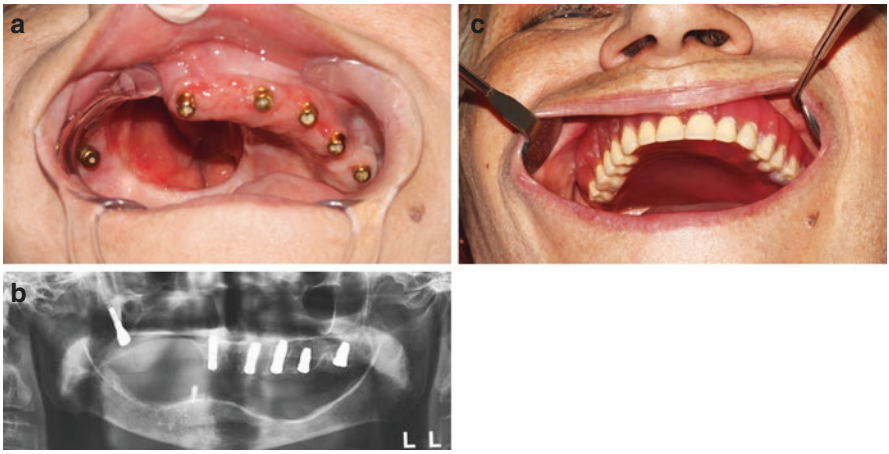

Fig. 22 Pterygoid implant used in this patient who has had partial maxillectomy to provide cross arch support and stability for a denture/obturator (**a**). OPG after implant placement (**b**). Prosthesis in place (**c**)

3.3 Tilted Trans-Sinus Implants

Using tilted implants in the atrophied maxilla or mandible allows for longer anterior-posterior (AP) spread of the final prosthesis, when desirable bone anchorage exists only close to the midline [63]. In a patient with maxillary atrophy who is going to receive a fixed prosthesis on four implants, the two anterior implants will usually be placed parallel to each other and the sagittal plane in the central or lateral incisor region on each side. The longer distal implants will enter the alveolar bone with a 30-degree angle as close as possible to the second premolar region while their apexes are located where the canine apex is supposed to be. This design eliminates the need for sinus bone grafting and potentiates immediate loading of the implants if the insertion torque is above 30 Ncm.

In the case of mild to moderate atrophy with posterior pneumatization of the maxillary sinus, the tilted distal implants might be placed entirely in the alveolar bone. However, in patients with severe atrophy where the sinus has extended more anteriorly as well as toward the alveolar crest, a portion of the tilted distal implant will inevitably enter the sinus and the alveolar bone alone will be insufficient to create a high enough primary stability for immediate loading. In this scenario, the bony anchorage of the distal implant can be attained by the cortical bone located in the lateral nasal wall known as the M point. This area of hard cortical bone is usually 2 mm thick and is less subject to the atrophy taking place in the alveolar bone [64]. Placing a tilted 15–20 mm implant at the M point is considered a less aggressive alternative for dental implantation of the atrophied maxilla in comparison with zygomatic implants.

The surgical technique for placing tilted trans-sinus implants involves a lateral window preparation extending mesio-distally from the anterior sinus wall to the entrance point of the implant and with enough height to facilitate elevation of the Schneiderian membrane from the sinus floor and the anterior sinus wall. Grafting the sinus is deemed unnecessary and is only recommended if proper engagement of the implant in the M point is not achieved and loading is postponed to 3 months after surgery.

Most complications concerning trans-sinus implants pertain to the prosthetic phase including screw loosening and fracture. Sinus infection has rarely been reported in placing trans-sinus implants and when compared to zygomatic implants, sinus complications are much less prevalent. Other biologic complications include preimplantitis and mucositis. Failure in placing the implant in the cortical bone at the M point can lead to loss of primary stability and subsequent loss of implant. The success rate of trans-sinus implants with a 3-year follow-up has been reported to be more than 95% by Malo et al. [65].

3.4 Ultrashort Implants

Implants with 6 mm or less length with improved surface characteristics have been applied as an alternative to placing longer implants after sinus floor elevation in patients with maxillary atrophy. In a review conducted by Qi Yan et al. the survival rate of short implant was reported to be more than 99% in a longer than 3-year follow-up, a figure which exceeds the survival rate of longer implants placed after sinus elevation surgery [66].

Placing ultrashort implants is inherently simpler than carrying out a sinus grafting procedure prior to implantation, given adequate bone width exists. Also, these implants reduce the occurrence of complications. Since there is no need for sinus grafting, sinus complications including membrane perforations and postoperative sinusitis is a rarity after ultrashort implant placement. The most common complication, with mostly anecdotal report rather than published evidence, is migration of implants into the antrum probably due to inadequate presurgical evaluation of remaining bone height. Short-term reviews show ultrashort implants can successfully support single crowns in posterior maxilla [67], yet still clinicians have the concern that gradual bone resorption around the implant might lead to their earlier failure. As using ultrashort implants is one of the newest modifications in dental implant treatment planning, future long-term clinical trials and reviews will shine more light on the advantages and complications of this treatment modality.

4 Augmentation with Onlay and Inlay Autogenous Graft

Occlusal rehabilitation of a severely atrophic maxilla with implants was accomplished by autogenous bone grafting before non-graft techniques were introduced. Graftless techniques including zygomatic implants and ultrashort implants have shown short-term success, yet their long-term results still need to be examined and they are subject to a bevy of complications such as problems pertaining to location of prosthetic elements, speech and hygiene. Therefore, reconstructing ridge height and width by autogenous graft is still a go-to treatment option in many cases. Since the amount of bone required for bone augmentation cannot be sufficiently harvested from intraoral resources, extraoral sites such as the anterior iliac crest and calvarial bone are mostly utilized for this purpose [68–70].

Complications related to harvesting bone from the anterior iliac crest or the calvaria are rare and generally avoidable with proper technique and planning. Intraoperative bleeding and postoperative hematoma are probably the main concerns. Meticulous surgical technique and preventive measures such as covering exposed

spongious bone at the donor site with bone wax and using vacuum drains can help keep morbidity to a minimum and prevent post op hematoma. Other complications reported in the literature include nerve injury, potential intracranial injury, abdominal hernia, cosmetic deformity, consistent pain, and deep vein thrombosis [71, 72].

At the recipient site, the main concerns are infection, wound dehiscence, and resorption. All patients receiving these treatments should receive prophylactic antibiotics prior to surgery and systemic antibiotics in the postoperative period. Proper fixation of the graft is crucial for its success and it is best achieved by titanium micro and mini screws and plates.

Primary closure of the incisions with tension-free flaps is another important ingredient for achieving optimal results in this procedure. The intraoral full-thickness incision to expose the recipient site can be placed either just palatal to the alveolar crest or deep in the labial and buccal vestibule. Both designs help keep the incision away from the grafted bone. The former is easier to elevate and has little effect on the depth of the vestibule, but it is more difficult to suture. The Latter allows for a two-layer closure, since the incision cuts through the oral mucosa and the remnants of the orbicularis oris deep in the vestibule, yet it mandates an additional vestibuloplasty procedure later on as it distorts the depth of the labial and buccal vestibule. Vertical mattress sutures are recommended for the final closure regardless of the incision design.

Another complicating condition is the lack of adequate keratinized gingiva labial and buccal to the grafted ridge. To assure tension-free closure, the labial flap is usually advanced toward the crestal incision and this results in non-keratinized and unattached mucosa to traverse all the way to the crest of the ridge.

Using free gingival grafts (FGG) harvested from the palate can provide the necessary keratinized gingiva buccal to the implants; yet the palatal mucosa is not abundant and for cases of full mouth reconstruction, grafting might need to be done in more than one stage.

A more practical technique is transferring the keratinized palatal gingiva to the buccal side using a buccally positioned flap. This can be conveniently done at the second-stage surgery when healing abutments are loaded on the implants. In this technique, a beveled incision is placed palatal to the alveolar crest, starting supraperiosteally and then becoming a full-thickness flap at the alveolar crest and the flap is elevated with a buccal base. Then, healing abutments are loaded on the implants and the flap is sutured remaining in the buccal side of the healing abutments. Secondary healing of the incised area is facilitated as the periosteum remaining below the beveled incision help with the induction of fibroblast necessary for healing. After 2 weeks the sutures can be removed and the prosthetic phase of the treatment can begin (Fig. 23).

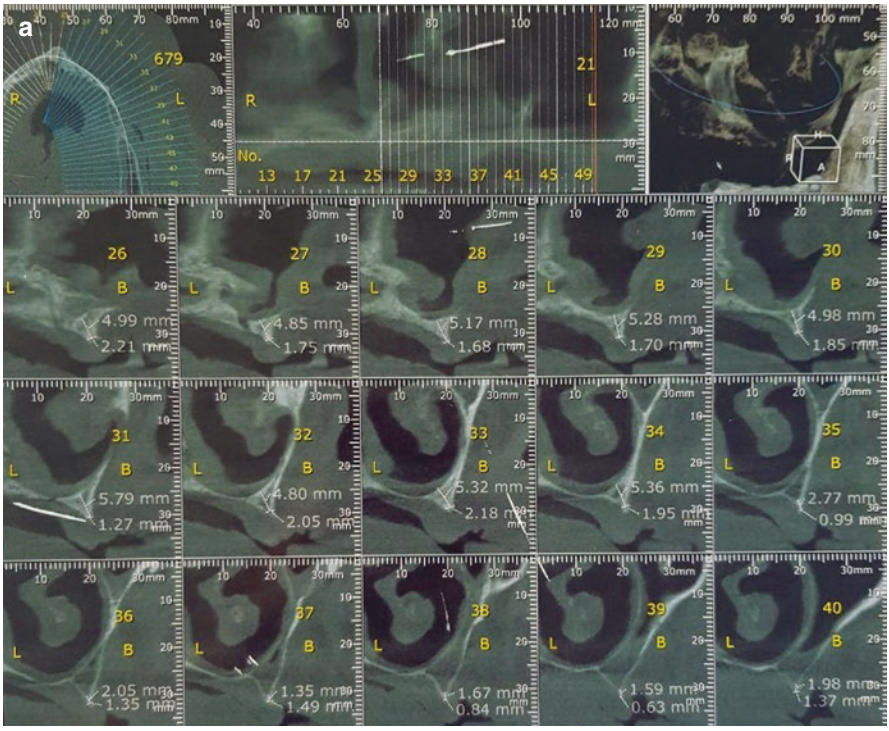

Fig. 23 CBCT of patient with severe maxillary alveolar ridge atrophy. Note the insufficient bone width and height (**a**). A full-thickness mucoperiosteal flap is elevated to expose the maxillary bone (**b**). Cortico-cancelous bone is harvested from the anterior illiac crest. Cortico-cancelous bone blocks harvested from the anterior illiac crest are fixated on the maxilla with titanium miniscrews to augment bone width and height. The buccal fat is approached and pulled over the grafted sites while preserving its intact pedicle for blood supply to boost soft tissue healing and increase the chances for graft survival (**d**, **e**). Platelet-rich fibrin (PRF) plugs derived from the patient's centrifuged blood sample are prepared and placed over anterior grafted sites where the buccal fat could not reach (**f**). Grafted cortico-cancelous bone blocks covered with bilateral buccal fat grafts and PRF plugs (**g**). Healed soft tissue 3 months after the operation. Note the lack of adequate keratinized gingiva buccal to the alveolar crest (**h**). Post-op OPG after bone grafting (**i**). In the second-stage surgery, palatal keratinized gingiva is transferred to the buccal of the healing abutments by a beveled incision placed palatal to the alveolar crest. The gaps between the keratinized tissues will heal secondarily (**j**, **k**). Post-op OPG after implantation (**l**)

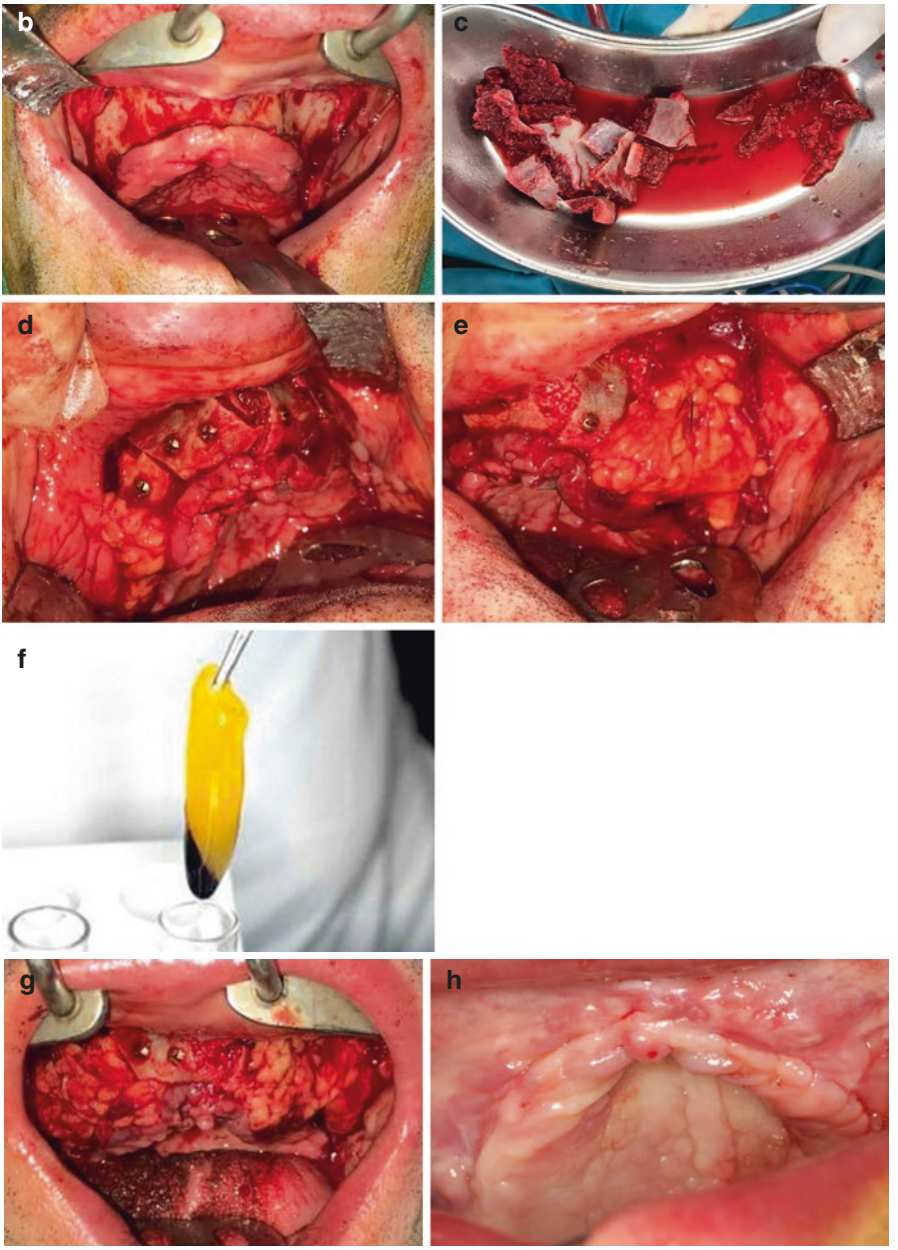

Fig. 23 (continued)

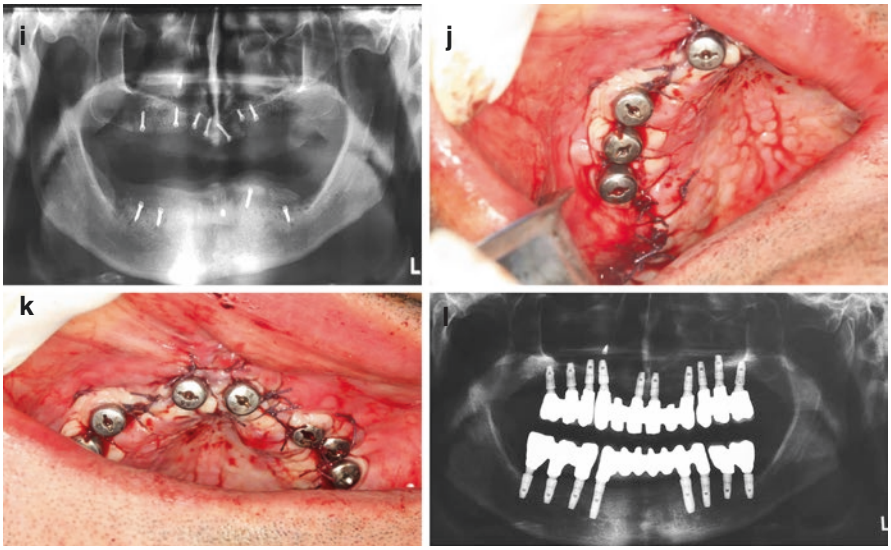

Fig. 23 (continued)

5 Conclusion

The key to minimizing complications during or after any treatment is comprehensive presurgical planning and evaluation, but even when a seasoned surgeon is practicing a well-established technique, complications, and unexpected problems might inevitably arise and practitioners must be trained to manage complications once they occur. In the case of occlusal rehabilitation of the atrophied maxilla with dental implants many recent techniques have been developed with the aim to reduce treatment time, cost and morbidity for which a comprehensive literature of scientific reports with long-term follow-ups does not yet exist. Practitioners who venture in new realms and use relatively newer techniques must stay up-to-date and train themselves in the knowledge and skills necessary for managing risks and complications pertaining to each technique.

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Miscellaneous Complications in Oral Implant Surgery

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1 Introduction

Implant surgery is commonly accounted for as a smooth yet precise procedure. It is frequently reported that dental implants have higher than 95 % success rate in 10-year follow ups [Howe MS et al. 2019]. Most patients have only heard about the high success rates and the safety of the implant procedures as well as the new imaging and digital treatment planning systems. Therefore, sometimes even minor complications seem unacceptable and frustrating for the implant patients [Pjetursson BE and Heimisdottir K 2018]. This chapter will give an overview of some of the very important implant complications that are not usually discussed in major complication categories and are frequently underestimated. We will start from complications stemming from preoperative evaluations, and then will review the complications caused by treatment planning. Finally, the controversies regarding titanium toxicity and allergic reactions will be discussed. The main focus of our chapter would be the prevention, diagnosis, and management of each complication.

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2 Inadequate Evaluation

Each implant patient needs a comprehensive preoperative evaluation. Many implantologists spend several hours analyzing CBCTs and using state of the art technology to treatment plan and fabricate surgical guides. Surprisingly, however, it is not uncommon to see that some basic review of medical history, discussion of idealistic versus realistic patient expectations, and clinical evaluations are missed or forgotten. Therefore, some unusual complications may happen even before starting the surgery (Figs. 1a,b and 2).

2.1 Implant in Existing Tooth Remnants and/or Pathologic Lesions

It seems very unlikely to see an implant where there are pre-existing tooth remnants and/or pathologic lesions. But assume that a patient is referred to you with a high-resolution Panoramic X-ray or a CBCT and a letter indicating that some teeth are extracted due to pain. Root remnants smaller than a few millimeters may remain asymptomatic without the need to be retrieved but will lead to serious complications and failures when in contact with an implant. It is therefore important to obtain new imaging for each new treatment plan. It is of paramount importance to thoroughly review the past medical history and allergies, conduct a thorough intraoral exam, and discuss potential concerns and risk, benefits, and alternatives of treatments with patients in the initial appointments. Direct intraoral examinations under adequate light and palpation of ridges as well as the evaluation of cast models should be an integral part of implant treatment planning.

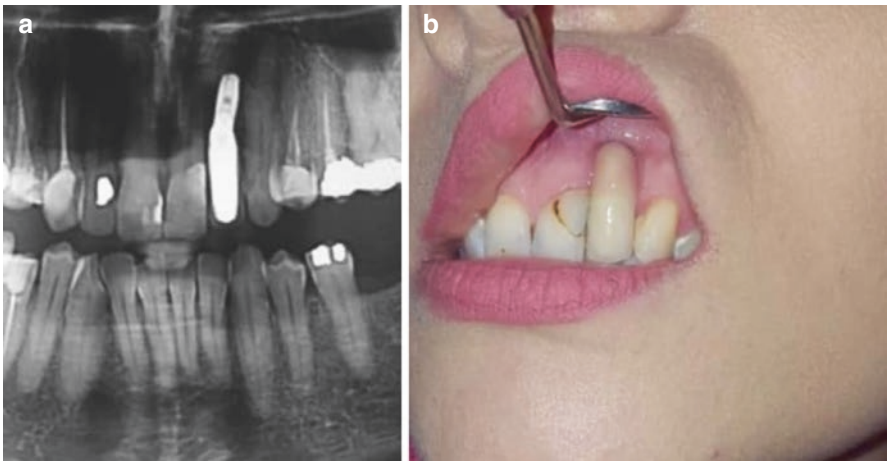


Fig. 1 (**a**, **b**) A well-integrated, non-restorable implant. This situation can easily be detected preoperatively

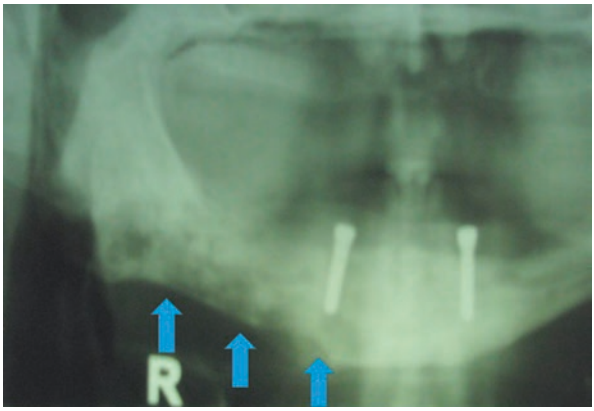


Fig. 2 Inadequate preoperative evaluations. Two well-integrated implants in the huge pre-existing pathologic lesion (look at blue arrows)

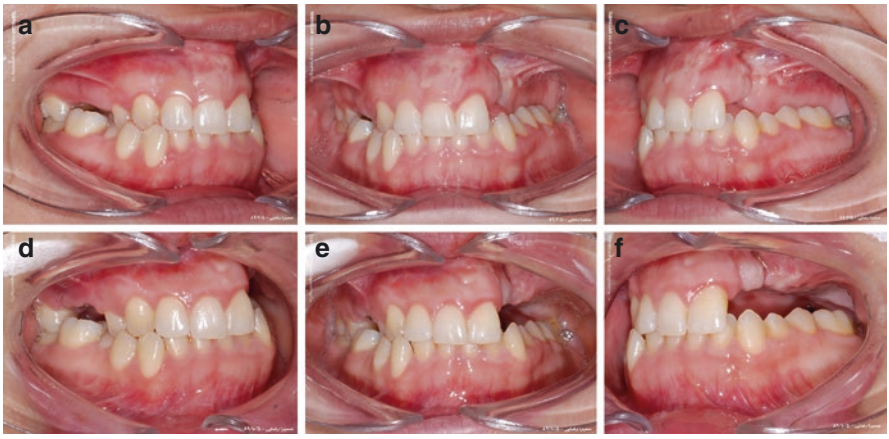


Fig. 3 (**a–c**) Inadequate inter-arch space is easily diagnosed in preoperative evaluations. (**d–f**) Either segmental osteotomy or reductive osteoplasty may correct the situation

3 Nonrestorable Implants

Lack of adequate space to fabricate restorations will render well-integrated implants of appropriate size and position nonrestorable as will the lack of opposing dentition to restore the function of the dental implant. As a rule of thumb, a minimum of 7 mm is needed for the fabrication of cemented crowns. This height is 5 mm if screw-retained crowns are planned [Greenstein G et al. 2019]. In most cases, when there is an adequate amount of bone, ridge remodeling and reshaping during the surgery would be the easiest way to create space. When the bone height does not let bone trimming, segmental osteotomy and repositioning of the recipient site may be performed (Kassolis JD et al. 2003) (Fig. 3a–g)

Key points in the prevention of complications due to inadequate evaluations:

- Comprehensive clinical examination is the mainstay of success in dental implantology.
- Tridimensional imaging and computer-guided surgeries are not substitutes for thorough clinical examinations and history taking.

4 Improper Treatment Planning

Treatment planning is the backbone of successful dental implantation. Despite all the challenges and controversies in implantology, treatment planning should always be based on best evidence. Patients are to be informed about the different options and the known pros and cons of each approach. More importantly, clinicians should be an expert in delivering the planned treatment [Wood MR and Vermilyea SG 2004]. In brief, treatment planning is an extremely unforgiving stage of implant therapy where the smallest of mistakes may culminate in significant complications.

The followings are the main complications encountered due to aerating planning:

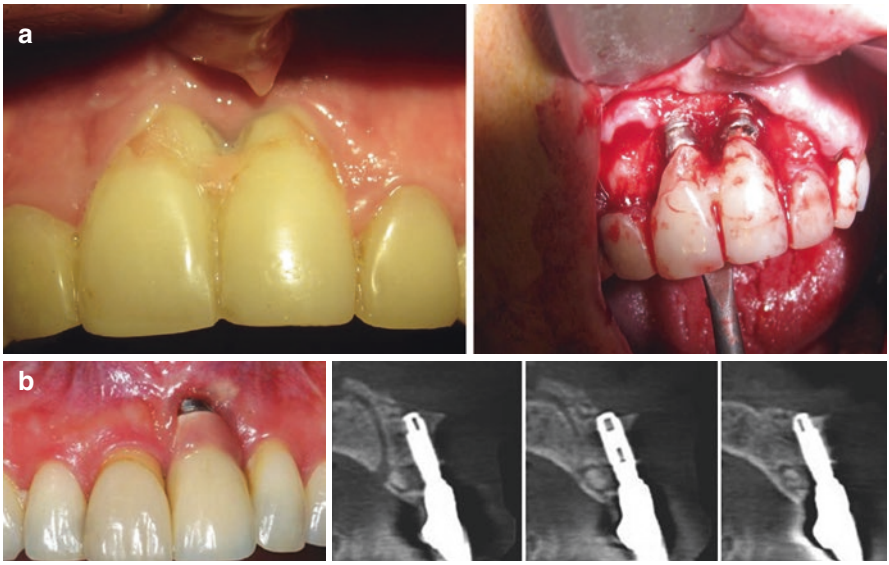
4.1 Complications Due to Inappropriate Implant Size and Number of Dental Implants

Determining the size and number of implants is an important part of treatment planning [Jung RE et al. 2018; Ortega-Oller I et al. 2014]. A longstanding implantology myth is that to achieve optimal results, the maximum number of implants with the biggest sizes should be placed. On the other hand, some clinicians try to bypass complex pre-implant procedures by using short and/or narrower implants inappropriately. Both of these concepts may cause significant complications.

5 Size of Dental Implants

A simple mathematical calculation shows that each additional 1 mm increase in length adds 8% and each 1 mm increase in width adds 20–30% to the surface area of implant. On the other hand, a minimum of 2 mm from the adjacent tooth and a minimum of 3 mm from an adjacent implant are needed to achieve optimal integration and to save papilla and interproximal bones. For example, for a 4 mm implant at least an 8 mm mesiodistal space would be needed in a tooth-borne space [Greenstein G et al. 2019]. Violation of this requirement with an oversized implant may result in osseointegration failures or gingival recessions challenging to be managed (Figs. 4 and 5a,b).

Regarding the length, longer implants logically provide a wider surface area which is expected to increase primary stability. Therefore, longer implants are believed to increase predictability and the long-term stability of implants especially in higher porosity bone. Meanwhile, major anatomic elements in maxillary and



Figs. 4 and 5 (**a**, **b**) Big size implant, in improper position has destroyed papilla, buccal bone, and interplant bone. This serious complication may need the explanation of implants and wide reconstructions before the replacement of implants

mandibular arched are to be avoided with a minimum recommended safe distance when choosing longer implants. Moreover, some clinicians believe that sufficient cooling of osteotomy site is more challenging in longer implants and therefore it is very difficult to have a safe and precise bone preparation. Consistently, increased implant length may result in complications such as periapical implant lesions [retrograde perimplantitis]. It is believed that 12 mm is the longest implant that may be safely placed in routine implant surgery [Romanos GE et al. 2011; Qu C et al. 2014; Jalbout ZN and Tarnow DP 2001].

Short implants are extensively discussed in the literature. Current evidence shows that short implants are a completely valid option in implant dentistry and may easily eliminate many potential complications associated with regular implant placement. These implants reduce the need for complex surgical procedures and need less skill and expertise. Short implants have shown high success and low complication rates. As a result, implantologists have confidently incorporated shorter fixtures in their practice, switching from fixtures of less than 10 mm to those of less than 8 mm and, most recently, less than 6 mm in length [Jung RE et al. 2019; Altaib FH et al. 2019].

The key points in avoiding implant size complications:

- Interproximal bone and papillae need enough space to survive.
- Longer implants need more precise bone preparation and more attention to cooling during osteotomy to prevent retrograde periimplantitis.
- Wide, narrow, and short implants are valid treatment options if used as indicated.
- Short implants (less than 6 mm) are acceptable options when used cautiously.

6 Numbers of Dental Implants

There is no consensus on the ideal number of dental implants for the restoration of fully or partially edentulous patients. There are, however, some basic rules of thumb that may help avoid complications [de Luna Gomes JM et al. 2019; Daudt Polido W et al. 2018].

Key points in avoiding implant number complications are:

- An excessive number of implants do not guarantee a higher success rate (Fig. 6).
- An excessive number of implants increases the rate of complications and jeopardizes bone and soft tissue health (Fig. 7).
- Four to six implants seem to be enough for full mouth rehabilitation.
- Two implants would be enough to restore four missing anterior maxillary teeth.

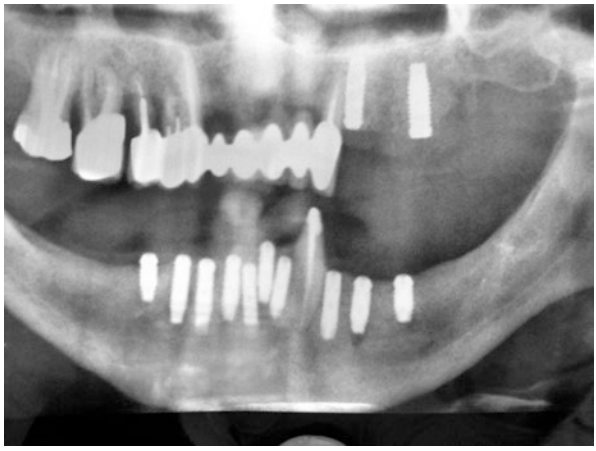


Fig. 6 The excessive number of implant that has destroyed the inter-implant bone

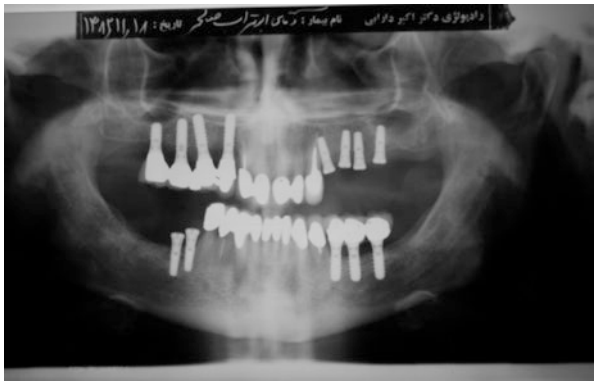


Fig. 7 The excessive number of the implant may increase the rate of complications. As in this case, adjacent tooth damage has happened

7 Implant–Tooth Connection: An Evidence-Based Approach

Connecting an implant to a natural tooth might sometimes be a very appealing idea. This seemingly simple treatment plan may potentially reduce the total cost of treatment, increase safety with avoiding anatomic landmarks, reduce the complexity of the surgical procedures, and in brief, provide more options to an implant candidate. Historically, however, many clinicians have discouraged attaching a tooth to an implant. They have argued that a tooth has about ten times more mobility compared to an integrated implant and this difference will lead to complications and failures.

On the other hand, many well-designed studies have provided evidence that the complications and failures in this treatment plan are overstated, proposing the tooth-to-implant connection as a predictable restorative approach. While these studies highlight that such bridging does potentially result in some complications, they suggest that most of these complications are predictably manageable postoperatively without a significantly reducing the overall success rate [Al-Omiri MK et al. 2017; Davis SM et al. 2014; Hoffmann O and Zafiropoulos GG; Mamalis A et al. 2012].

Generally, the complications associated with the tooth to implant bridging may be divided into biological and mechanical (Figs. 8 and 9).

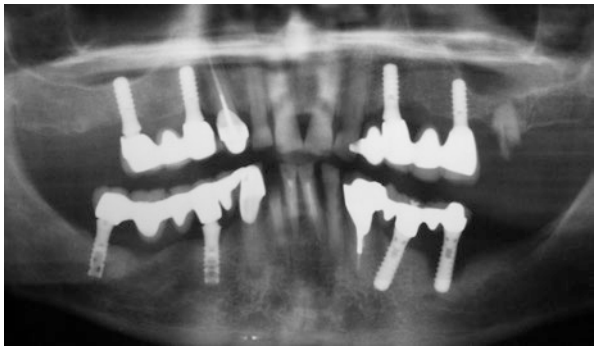


Fig. 8 Improper tooth to implant splint. Incorrect planning has led to carious abutment teeth and whole treatment failures

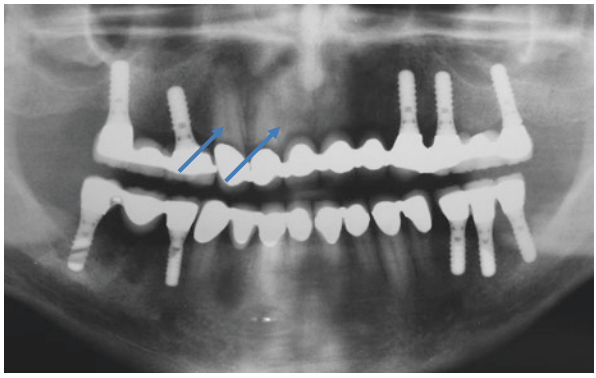


Fig. 9 Improper tooth to implant splint. Incorrect treatment planning and maintenance has resulted in sever pre-implant bone loss

8 Technical Complications

Technical complications include any mechanical damage to the implant, implant components, or teeth. Some authors have proposed using different types of non-rigid connections to counter the difference in tooth versus implant resilience to prevent technical complications. However, many studies have shown that these connections remove the stress from the superstructure and transfer it to the implant and the tooth. Therefore, in non-rigid connections, many cases of bone loss and tooth intrusion have been reported (Fig. 10).

9 Tooth Intrusion

The intrusion of the natural tooth is a relatively common complication of tooth-to-implant connection, estimated to happen in 3–5% of tooth-to-implant bridged cases. Moreover, 50% of patients with these intrusions have a history of bruxism. The exact mechanism of intrusion, however, is not well understood. The common belief is that when a tooth is splinted to an integrated implant, the PDL will go through disuse atrophy and, as a result, the connected tooth will move inwards. It is believed that this complication should be detected in regular post-op visits and corrected restoratively.

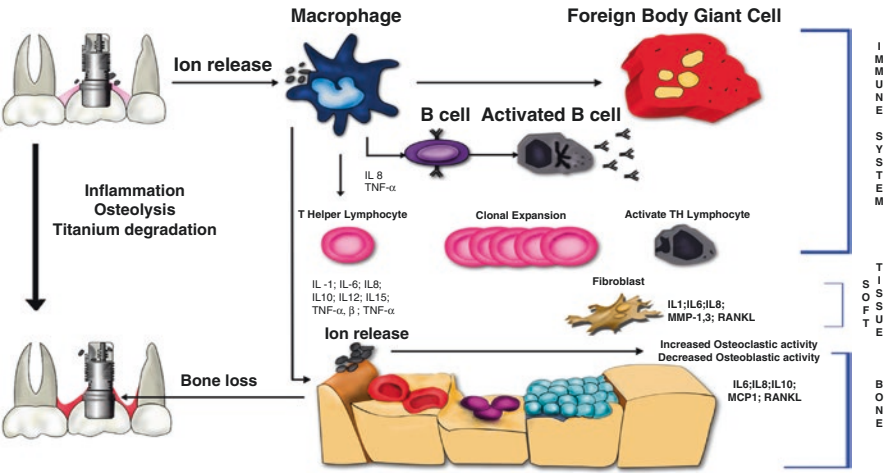


Fig. 10 Schematics of the titanium degradation process and subsequent bone loss. [From Sammy Noumbissi, Antonio Scarano, and Saurabh Gupta Journal of Materials Feb 2019, by permission] Miscellaneous Complications in Oral Implant Surgery

10 Biological Complications

Periimplantitis, bone loss around the teeth, and tooth or implant loss are some of the most reported biological complications of tooth-to-implant connection.

Key points in the prevention and management of complications related to the tooth to implant bridging are:

- There is emerging evidence in support of tooth-to-implant connection.
- Tooth-to-implant bridging has its risks and is not usually accounted for as the first restorative choice.
- Structural compromise such as endodontic treatment and presence of post and core, as well as periodontal involvement dramatically increase the rate of complications.
- Suboptimal implants such as short and/or narrow implants and implants placed in lower quality bone are likely to negatively affect long-term prognosis of the treatment.
- Proper maintenance is the mainstay in having a successful tooth-to-implant bridging.
- Both patients and implantologist should be ready for unscheduled visits to manage a complication.
- The intrusion of teeth, bone loss around implants, and porcelain chipping are the main complications in tooth to implant bridging.

11 Toxicity of Titanium Dental Implants

It is estimated that more than a thousand tons of titanium is implanted in humans around the world each year. Titanium and titanium alloys are generally considered nontoxic biocompatible biomaterials. The surface of titanium and titanium alloys oxidize immediately upon exposure to air or body fluids, a process called passivation. This phenomenon prevents release of metallic ions and considerably enhances the biocompatibility of dental implants.

On the other hand, titanium is also widely used in cosmetic as well as food industries. This means that most people are vastly exposed to titanium from variable sources [Fage SW and Muris J 2016] Recent studies have shown that titanium implants might release metal particles to the surrounding tissue. This attrition may happen as early as the placement surgery up to many years after a successful restoration [Delgado-Ruiz R and Romanos G 2018] and metallic deposits may be traced in bone, kidney, liver, brain, and lungs of implant patients [Přikrylová J et al. 2019]. However, it is still believed that dental implants do not release significant amounts of metal particles, and even if they release small amounts, it would have no important clinical implications. The main focus here is to give an overview of the current literature on the potential attrition of metal particles from dental implants and briefly touch on the rather rare toxicity attributed to such particle release.

12 Metallic Attrition

12.1 Metal Release During Drilling and Osteotomy

Implant drills undergo friction, wear, and attrition, and release different metallic particles to the osteotomy sites. It has been shown that these particles might easily deposit to adjacent bone and after a short time, hematogenously spread to kidneys, lungs, and liver. Frequent sterilization of drills, the number of time they are used, and the use of surgical guides directly increase the amount of these released metallic debris. Piezosurgery appliances have shown to result in even higher metal attritions in implant site preparations in vitro. However, in vitro studies have shown that even in case of material attrition during osteotomy, these particles are mostly detected in the irrigation solution and are rather removed from the surgery site. Therefore, the use of copious irrigation may not be overlooked in dramatically decreasing the amount of attrition from implant osteotomies [Delgado-Ruiz R and Romanos G 2018; Rashad A et al. 2013].

12.2 Metal Attrition During Implant Placement

Insertion of the implant poses shearing stress and friction on the implant surface and may cause micro-attrition of titanium particles as discussed above. It is shown that each implant insertion can release up to 0.5 mg of metal and metallic ions to adjacent tissues. New generations of dental implants receive more complex surface treatments which may increase their surface roughness and potentially cause more wear and corrosion in the microstructures. Furthermore, the macrostructure of dental implants may also considerably influence metal release. Schliephake et al. found that insertion of self-tapping implants makes microfractures on bone and abrades implant surfaces, potentially accelerating particle release and dissemination [Delgado-Ruiz R and Romanos G 2018].

12.3 Metal Release in Abutment Fixture Connections

Implant and abutment connection are subject to wearing and subsequent release of metal particles to adjacent tissues. Utilizing two different metals may potentially cause further corrosion of weaker metal and potentially provoke foreign body reactions [Delgado-Ruiz R and Romanos G 2018]

12.4 Metal Release in the Maintenance Phase

There is no single standard method used in the maintenance of dental implants. Meanwhile, it is clearly shown that all methods from plastic scalers, metallic instruments, implantoplasty, chemical solutions, and even LASER decontaminations are

likely to change titanium surface structure and cause ionization into the adjacent tissue [Delgado-Ruiz R and Romanos G 2018].

12.5 Proposed Local Adverse Effects of Titanium Implants

Despite the attrition and ionization, there is no exact definition for titanium implant toxicity. In fact, this is an emerging term that has recently be used in some studies to challenge the inertness of titanium implants and to highlight the rather rare, clinically significant, unwanted local and systemic effects of dental implants. Some authors have suggested that small particles may initiate immune reactions with different mechanisms and may lead to bone loss, periimplantitis, or even unexplained implant failure. This concept confronts traditional belief in the microbial etiology of periimplantitis and implant failure and suggests foreign body and immune reactions as the mechanism of periimplantitis and implant failure [Frydman A and Simonian K 2014; Kim KT et al. 2019; Eger M et al. 2018].

13 Proposed Rare Systemic Adverse Effects of Titanium

There are sporadic reports of systemic adverse effects of non-dental titanium implants [Kim KT et al. 2019]. Berglund and Carlmark reported a case of yellow nail syndrome in one of their knee implant patients. This is a rare medical condition characterized by nail changes, lymphedema, maxillary sinusitis, and respiratory tract involvements. This complication happened a few months after placement of the knee implant, spontaneously resolved after implant removal, and recurred after re-insertion of a new implant [Berglund F and Carlmark B 1999; Berglund F and Carlmark B 2012]. These authors in 2011 proposed the possible role of titanium in this rare syndrome.

Key points in prevention and management of ion release and metal toxicity:

- Metal release to tissues is present but does not seem to be associated with clinically significant consequences for the most part.
- Use of disposable drills may effectively reduce metal particle attrition. So will the periodic changing of drills and disposal of blunted worn drills.
- Intraoperative copious irrigation and strong suction is likely to adequately eliminate the bulk of osteotomy micro-attrition.
- Rare systemic complications are unlikely with dental implants but such complications are best to be referred for medical management.

14 Allergy to Dental Implants

Sensitivity to metals is extensively discussed in the medical literature. It is estimated that about 15% of North Americans and about 20% of the western European population has some kind of allergy to metallic contents [Kounis NG and Koniari I 2018]

Metal hypersensitivities are commonly cell-mediated type IV reactions. To initiate a type IV hypersensitivity, metallic ions should bind with a native body protein to make a hapten antigenic complex. When second exposures happen, T cells produce cytokines which cause late hypersensitivity signs and symptoms. Titanium allergy may induce a wide range of general symptoms such as depression, fatigue, fibromyalgia, and intraoral symptoms like lichenoid drug reactions, unexplained pain on implant site, eczema on face, and more importantly unexplained failures of dental implants. Despite these facts, the general belief still considers titanium an inert biomaterial that rarely causes allergic reactions [Kounis NG and Koniari I 2018; Přikrylová J et al. 2019]. Titanium implants oxidize superficially immediately after exposure to air or body fluids. Titanium oxide, the superficial layer of dental implants, is water insoluble and does not bind with body protein and cells. However, as explained above, metallic micro-attrition and ionization occur in all steps of implant dentistry. It is not clear if these particles would sensitize the immune system and provoke hypersensitivity [Chaubey AK et al. 2019; Sicilia A et al. 2008; Siddiqi A et al. 2011].

14.1 Diagnosis of Titanium Allergy

Diagnosis of titanium allergy is mainly based on medical history and clinical findings and may be confirmed by immunologic tests. The patch test is the main diagnostic measure used for type IV hypersensitivity reactions. In this test, an extract of the allergen in question is used to assess potential triggering of a local reaction much like a tuberculin test. The lymphocyte transformation test, the lymphocyte migration inhibition test, and the commercially available memory lymphocyte immunostimulation assay (MELISA®) tests are frequently reported to be used to detect allergy to titanium implants. It should however be noted that none of the tests are considered the gold standard due to their limitations, validity and reliability, and cost.

14.1.1 Management of Patients with Allergy to Titanium

Allergy to titanium is a relatively new topic in dental implantology. Therefore, there is no consistent data for the diagnosis and management of potentially allergic patients and many clinicians use medical literature to address the issue. Pacheo KA believes that two groups of implant patients need special attention regarding titanium allergy and are best to be sent for immunologic tests before proceeding with a titanium implant placement. In the first group, patents have a clear history of metal allergy and a simple medical history questioner will identify these patients. The other group is patients with unexplained prior non-dental titanium implant failures. Unexplained and aseptic implant failures are frequently attributed to hypersensitivity reactions. When clear positive sensitivity is reported, alternative implant materials may be used. Zirconium dental implants are promising alternative implants that may substitute titanium in allergic cases.

Key points in prevention and management of allergy to implants:

- The trigger point in an allergy to implant metal might rather be sensitization by the released or ionized particles.

- Precise surgical techniques, use of sharp drills, copious irrigation and strict maintenance regimens may effectively prevent or manage metallic attrition.
- Inquiring about allergy to metals should be an integral part of history taking and patients with reasonable suspicion should be referred for further evaluations.
- In multiple unexplained failures, allergy to titanium may be considered and further workup may be warranted.
- Pain, fatigue, eczema, redness on the skin, and yellow nail and any other signs and symptoms after implant surgery may notify a possible sensitivity and are best not be ignored.
- In highly suspicious patients and known titanium allergy, alternative implants such as geh
- advocated

Further Reading

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