Implants in the Aesthetic Zone

A Guide for Treatment of the Partially Edentulous Patient

Todd R. Schoenbaum
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I would like to thank my amazing wife Amy for her support and patience during this project. Through her, and with her, all things are possible. I would also like to extend my deepest gratitude to the amazing scientists, clinicians, and technicians who contributed to this book. They were selected because they are unsurpassed in their expertise in the profession. I am forever in their debt. Lastly, I would like to thank you, the reader, for taking the time to read this text. It is my sincere hope that it contributes to you, your practice, and your patients.

Foreword

Aesthetics is commensurate with health and well-being, and this is no more true than when considering teeth and oral health. The absence of teeth, through trauma, disease, or genetic disturbance, is considered by many patients a form of disability. With the advent of dental implants, we, the dental profession, have the means of resolving these issues and improving the quality of life for our patients.

Dr. Todd Schoenbaum has succeeded in bringing together some of the master scholars within the field of implant dentistry, both surgeons and restorative clinicians. The contributors to this text come from all over the world; all have unique abilities that lie not only in treating patients in their clinics, but also the desire to pass on their knowledge and expertise. The intention is to provide the reader with a foundation to further expand their own capabilities and ultimately improve the treatment of those under our care.

Chandur P. K. Wadhwani

Preface

This text is intended to serve as a clinical guide for treatment of implants in the aesthetic zone. This area and treatment modality is uniquely complex in dentistry, requiring skill and expertise from surgeons, restorative clinicians, and technicians. Success requires a team approach. Here you will see I have assembled an unmatched group of authorities from around the world to assist you in this process. Each brings their unique expertise and experience to their work here. You will find these experts are straightforward and generous with their knowledge.

I hope you enjoy reading this book as much as we did in creating it.

> Do you think that I count the days? There is only one day left, always starting over: it is given to us at dawn and taken away from us at dusk.—Sartre

Los Angeles, CA, USA — Todd R. Schoenbaum

Contents

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Part I

Treatment Planning for Implants in the Aesthetic Zone

Treatment Planning for Implants in the Aesthetic Zone: Biological, Functional, and Aesthetic Considerations

1

Peter K. Moy, Todd R. Schoenbaum, and Sam Alawie

Abstract

Proper interdisciplinary treatment planning is the cornerstone of implant treatment in the aesthetic zone. It requires diligent and thoughtful consideration of surgical, prosthetic, and technical aspects of the care to be provided. Though some cases will present similar challenges, no two are identical. Patients will be best served when the clinicians and technicians involved on the case understand the challenges faced by the other team members. Additionally, depending on the severity of the defect, patient expectations may need to be tempered to accept the clinical realities of their case. The "team approach" is key here. Each member should know and be able to predict what the others are going to be doing during their treatment stage. Often an immediate load approach will be attempted in the aesthetic zone. This requires high-level coordination, collaboration, and communication.

1.1 Importance of Treatment Planning

The success with any dental implant treatment starts with an accurate and appropriately sequenced treatment plan. Brånemark (Fig. 1.1) first introduced osseointegration as a multidisciplinary effort and would only permit clinicians to train as a team

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Fig. 1.1 Dr. P.I. Brånemark is the key innovator responsible for the modern approach to implant dentistry. His work in the field of osseointegration of titanium implants has revolutionized current dental treatment

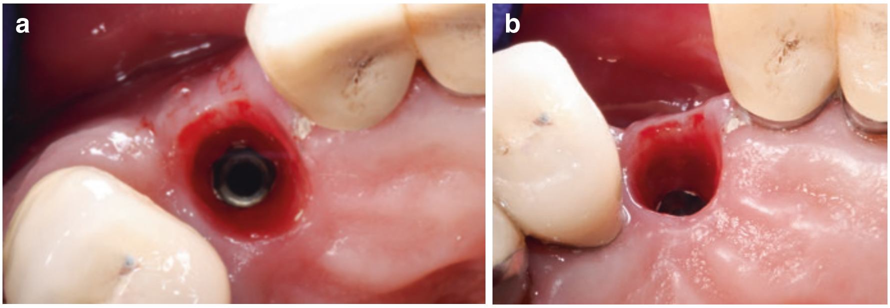

Fig. 1.2 (**a**, **b**) Peri-implant mucositis presents with various degrees of soft tissue pathologies, including inflammation, bleeding on probing, pus, fistula, and swelling

from both surgical and prosthodontic specialties. There are many factors to consider when treating the aesthetic zone with dental implants, even with a single missing tooth situation. Missing a single tooth in the aesthetic zone may often present as the most difficult and challenging to manage. The clinical assessment of the edentulous situation should be preceded by first identifying the cause of the edentulous state. If the cause for the loss of the tooth/teeth is not addressed first and corrected, once the implant is placed and has integrated, the alveolar defect that occurred and remains because of the tooth loss will lead to ongoing problems for the dental implant and implant-supported restoration. Ongoing problems such as inflammation of gingival tissues (better known as peri-implant mucositis) (Fig. 1.2a, b) leading to bone loss (peri-implantitis) (Fig. 1.3) will ultimately lead to the failure of the dental implant treatment. For example, if the tooth was lost due to trauma, there is often a concomitant loss of bone and/or soft tissues. If these deficiencies are present, an augmentation procedure or procedures should be performed first to restore lost tissues before placement of the dental implant. When the treatment is for the aesthetic zone, the best results occur when the alveolar ridges are ideally reconstructed to original contours and volume. This permits the ideal positioning of the implant during placement to best support the restoration. If the tooth was lost due to periodontal disease, not only must one worry about reconstructing lost hard and soft tissues but the periodontal status of the adjacent teeth and its effect on planned dental implant

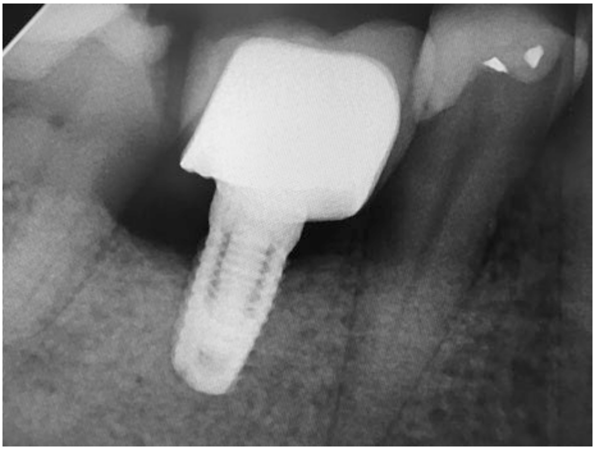

Fig. 1.3 Peri-implantitis is usually the result of untreated peri-implant mucositis. This results in a progression to atypical and aggressive bone loss around the implant. It may result in loss of the implant if unresolved

treatment must be accounted for. In a paper by Sgolastra et al. [1] using a systematic review of longitudinal prospective studies only, the authors identified strong evidence and with statistical significance that periodontitis is a risk factor for implant loss, moderate evidence and with statistical significance for periodontitis as a risk factor for peri-implantitis, and moderate evidence but not statistically significant for patients exhibiting periodontitis to experience greater peri-implant bone loss. For the aesthetic zone, the long-term outcome of implant treatment and maintenance of hard and soft tissue volume is extremely important in determining whether treatment was successful or not. A prosthetically driven, interdisciplinary, and systematic approach must be used if aesthetic risk factors are identified and managed accordingly [2].

1.2 Systematic and Interdisciplinary Approach

1.2.1 Medical Assessment

The implant patient's medical conditions will often affect the clinical outcomes of dental implant treatment, and the surgical specialist must be aware of these conditions so that preventative and/or corrective measures may be instituted to provide the implant patient with the best outcome. Several medical conditions are known to have negative effects on clinical outcomes with dental implant treatment [3]. Conditions such as diabetes, long-term steroid use, radiation therapy for oral-facial cancer, postmenopausal hormonal replacement therapy, and social habit (smoking) are associated with higher dental implant failure rates. The failures are due to delayed or poor healing of soft tissues typically related to poor vascularity resulting in exposure of the implant and surrounding bone structures. The 2005 article noted that although these medically related conditions present as relative contraindications for dental implant therapy, the overall failure rate of dental implants are low, and there are no absolute contraindications to implant placement. However, the medical conditions that present with increased risk for failure should be considered during treatment planning phase and included in the informed consent process. The implant patient with identified medical conditions that affect healing processes of hard and soft tissues must be made aware that their medical conditions should be stable or corrected prior to initiating implant treatment.

1.2.2 Dental Assessment

The dental assessment should include evaluation of the remaining dentition, how maintainable are the restorations, the periodontal status, and the volume of hard and soft tissues in the edentulous site and adjacent tooth structures. It is especially important to assess the dentition adjacent to the implant site. Residual infections from previous periapical abscess, periodontal disease, and/or soft tissue conditions where recession has exposed roots of adjacent teeth must be corrected.

1.2.3 Psychological (Patient MOTIVATION) Assessment

When the clinician is dealing with the aesthetic zone, the patient's expectations for treatment outcome must be understood. Once the clinician understands the patient's expectation, it is imperative that the clinician educate the patient on anticipated results and requirements for maintenance. Walia and coworkers [4] determined that a patient's seeking implant treatment (motivation) and their expectations (satisfaction at conclusion of treatment) with implant treatment differ. Patients today are more aware of dental implants as a viable treatment to replace missing teeth, thanks to large volume of available information on social media. However, the patients are not aware of the complications associated with implant treatment for the aesthetic zone, specifically the lack of hard and soft tissue volume as well as contours. There are varying reports on what patients are actually looking for when seeking implant treatment. Rustemeyer and Brernerich [5] identified 68% of women and 41% of men in their study felt aesthetics to be very important with their treatment results. In another study [6], the systematic review found the high cost of implant treatment often resulted in unrealistic expectations of the implant patient. Even with these concerns, Pjeteursson et al. [7] found in their 10-year prospective study that 90% of the patients were completely satisfied with implant therapy, both from a functional and aesthetic standpoint. The use of dental implants to restore missing teeth in the aesthetic zone requires the treating clinician to have a thorough understanding of what motivates the patient and what their expectations are at the completion of treatment. The potential for poor aesthetic results due to loss of interproximal papilla or hard tissue contours must be explained to the patient and the likelihood of this risk occurring. Included in the discussion is the need to surgically correct the deficiencies prior to implant placement.

1.3 Restorative Considerations for Treatment Planning Implants in the Aesthetic Zone

Our three primary concerns restoratively are functional, biological, and aesthetic (Table 1.1).

1.3.1 Functional Concerns

We must understand the risks of abutment failure, crown or FDP (fixed dental prosthesis; aka "bridge") failure, and screw breakage/loosening. Titanium and cast alloy abutments will have the least risk of breakage. The primary disadvantage of metal abutments in the aesthetic zone is discoloration of the soft tissues. Full contour zirconia abutments will generally have the highest risk of breakage (Fig 1.4a, b). The zirconia abutment luted to a "Ti Base" seems promising

Table 1.1 Restorative considerations for implants in the aesthetic zone

Functional concerns	Biological concerns	Aesthetic concerns
Abutment fracture	Risk of retained cement	Discoloration of the gingiva
Crown fracture	Reactions to metal alloys	Shade match for the crown
Screw fracture	Loose screws	Margin reveal
Screw loosening	Gingival recession	Gingival recession
	Poor fitting components	Screw access showing
	Porosities in the metal or ceramic materials	

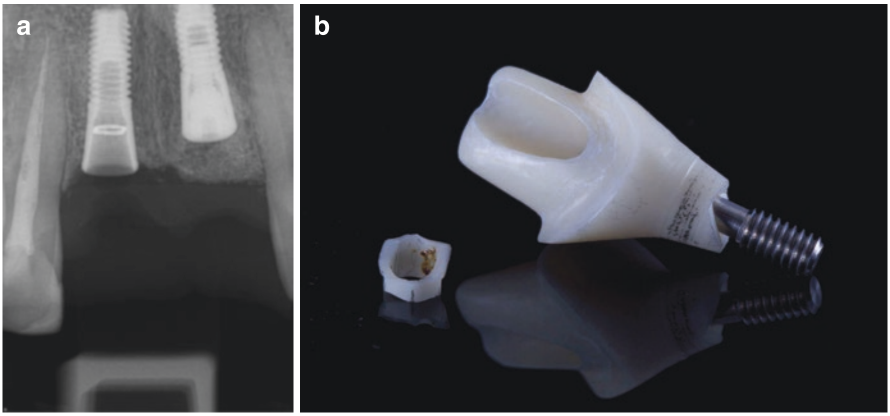

Fig. 1.4 (**a**, **b**) A full zirconia abutment has fractured inside the implant connection. The use of abutments without a Ti Base is risky due to this potential complication. The apical portion of the fractured zirconia abutment is visible on the radiograph as a radiopaque ring. Such fractures can be difficult to treat, as the remaining zirconia portion may be wedged in place requiring drilling to remove (courtesy of Dr. David Wagner)

Fig. 1.5 When zirconia abutments are indicated (generally due to high smile line and thin gingival biotype), they should be fabricated with a Ti Base. This helps to increase strength and minimize the challenges of retreatment should the abutment break

(Fig. 1.5). At the current time, there has only been one study looking at the strength of the Zr/Ti Base abutments [8]. This design appears to decrease the risk of breakage during cyclic loading; however, this is dependent on the implant being used, the Ti Base, the cementation protocol, the thickness of the zirconia, and the lab used to manufacture them. The take-home point being that not all Zr/Ti abutments are created equal. There are also an increasing amount of anecdotal reports of the zirconia abutment debonding from the Ti Base. While obviously problematic, this is relatively easy to resolve by re-bonding. The laboratory technician must ensure that the cementation protocols are properly followed and that the Ti Base is as long as possible. Far too many of these restorations seem to have insufficient height of the Ti Base.

An additional advantage of the Zr/Ti abutment is that, should the zirconia break, retrieval and removal is simple and predictable. This is in stark contrast to the failure of full zirconia abutments, which usually occurs at the neck of the implant connection. This leaves a small ring of zirconia inside the implant, which can be difficult to remove, especially in some tapered connections. The remaining Zr piece may have to be drilled out if it cannot be pulled out. This can cause significant damage to the connection interface in the implant. As such, full contour Zr abutments (without the Ti Base) should be avoided.

For the crowns on implants in the aesthetic zone, most of the modern ceramic materials appear to be strong enough. However, for scenarios requiring an FDP with a pontic, the lithium disilicate materials are generally best avoided due to an increased possibility of fracture at the connector. PFM (porcelain fused to metal) or PFZ (porcelain fused to zirconia) would be preferable options.

Loose and broken screws (Fig. 1.6) used to be a common occurrence and frustration. Improved alloys (i.e., Ti alloys replacing Au alloys), widespread use of torque wrenches (Fig. 1.7), and improved coatings on the screws have decreased the incidence of loosening somewhat. However, the great reduction in loosening and breakage is due to improved implant—abutment connections. The early root form implants with an external hex were not designed to retain single-unit prostheses. In

Fig. 1.6 Even modern titanium screws can fracture if they are improperly treated. Special care must be taken to ensure passive fit of the abutment and to not surpass the manufacturer torque values. The screw here was broken at delivery leaving the small threaded remnant to be carefully retrieved from inside the implant

Fig. 1.7 The use of a torque wrench is essential for delivery of implant restorations. They help the clinician ensure that the screw creates the proper pre-load without fatiguing the screw or implant. Most (but not all) screws are designed to be torqued to 30–35 Ncm

fact, the external hex was primarily designed to interface with the available drivers, and retaining a prosthesis was its secondary job. The external hex is generally less than 1 mm in height. This provides very little resistance and retention, placing all the off-angle force vectors on the screw, thus resulting in screws coming loose or breaking over time. So much so that it is generally advisable that all external hex implants be restored with a screw-retained restoration to allow for ease of screw replacement and re-torqueing.

There are hundreds of variants of internal connections currently available. Although they vary greatly in their engineering, as a general rule, they have a much more intimate and robust connection. This results in significant reductions in screw loosening. Some of these connections are so well designed that abutments can be difficult to remove even after the screw has been taken out. For restoring implants in the aesthetic zone, internal connection implants should be used. Additionally, most (but not all) data [9–12] show that a platform switch design will aid in maintaining peri-implant bone and soft tissue levels.

Occlusal management of implants in the aesthetic zone is critical to long-term success. Dr. Stevenson covers this topic in depth in Chap. 18.

1.3.2 Biological Concerns

First and foremost, the restoration selected/designed should impose a minimal risk in inducing peri-implantitis or peri-implant mucositis. Residual cement on the abutment is the most frequently discussed cause of peri-implantitis. While this is undeniably true, implementation of some relatively common sense guidelines mitigate this risk. Chief among these guidelines is that all abutments for cemented restorations should be custom milled, such that the margins are clearly accessible (Fig. 1.8) when the crown/prosthesis is cemented. See Chap. 14 for more information on the proper use of cemented restorations. It is important for the restoring dentist to understand the low-risk cementation protocols, because it is inevitable that patients will present with implants that do not allow for a traditional screw-retained restoration (Fig. 1.9a, b). The use of lingual set screws may serve as an alternative solution

Fig. 1.8 Margin placement is the crucial factor for using cemented implant restorations with minimal risk of retained cement and peri-implantitis. Here the Zr/Ti Base abutment was prescribed to have margin at −0.5 mm on the distal, facial, and mesial and at 0 mm on the palatal. This ensures easy access for cement removal and evaluation with little risk of aesthetic concerns

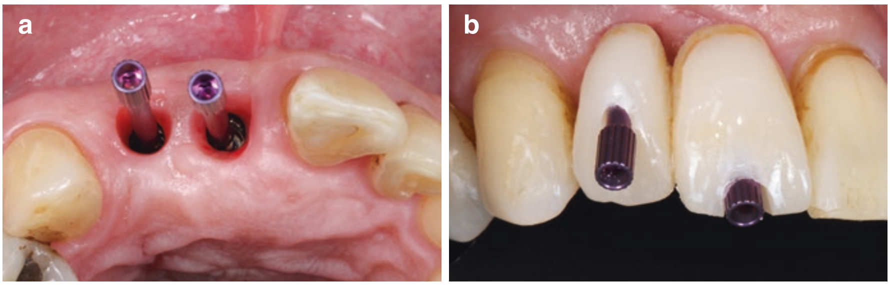

Fig. 1.9 (**a**, **b**) Unfortunately, not all implants are placed with access through the palatal, and not all manufacturers offer an angled screw channel option. Such cases are difficult to manage without a proper understanding of how to cement the restoration without the risk of retained cement on the abutment surface

to facially angled implants, but they are difficult to fabricate and have little to no evidence supporting their use. It should be well noted though that proper planning and surgical/restorative coordination *prior* to implant placement will minimize the frequency of such occurrences.

Additional prosthetic causes of peri-implantitis/mucositis include reactions to metal alloys, loose screws, poor fitting restorations and casted abutments (Fig. 1.10), poor fitting third party components, and porosities in the metal or ceramic materials. If left unresolved, peri-implant mucositis will lead to atypical bone loss around the implant.

The other area in which the restorative clinician affects the peri-implant biology is in the realm of abutment emergence profiles. The shape of the abutment where it joins the implant and as it emerges through the soft tissue will have significant effect on the health, cleansibility, and aesthetics of the peri-implant soft tissues. See Chap. 13 for more information on the design and effects of the abutment emergence profile.

Abutment cleanliness is also critical for the restorative clinician and technician to address prior to delivery of the prostheses. Most abutments and crowns regardless of design come out of the lab with significant amounts of particulate debris on their

Fig. 1.10 Poorly designed abutments and poor fitting restorations allow for bacterial reservoirs that induce peri-implantitis. Here the margins of the crowns have a significant marginal gap unfilled by cement. Thus allowing plaque and bacterial to accumulate, ultimately resulting in loss of the implants

surface. Canullo et al. recently published a survey [13] on how and if clinicians clean and disinfect prosthetic implant components. Worldwide there is huge variation in how this is done (steam, chlorhexidine, autoclave), and for the most part, the components are being placed into surgical implant sites without sufficient cleanliness. Even when cleaned as described above, the components still retain a significant amount of particulate debris. Preliminary studies have shown that proper cleaning of the abutments (with plasma of Argon) prior to placement can significantly increase the levels of retained bone around the implant. At a bare minimum, implant abutments and prostheses should be thoroughly steam cleaned and disinfected.

1.3.3 Aesthetic Considerations

The restorative aesthetic considerations for implants in the aesthetic zone are soft tissue color, soft tissue contour, and crown/prosthesis shade. The various studies examining the effects of abutment material on the perceived color of the soft tissues have failed to reach uniform conclusions. Most show that silver-colored metals (i.e., gold alloys, titanium) produce the greatest amount of discoloration of the gingiva, while ceramic-type materials (i.e., zirconia, lithium disilicate, alumina) produce the least color shift (Fig. 1.11). Of course with the use of ceramic-type abutment materials comes an increased risk of fracture not present with metals. As described in the *functional considerations* section above, the zirconia abutments should have a Ti Base design. This *functional risk* must be weighed against the aesthetic demands of the case. As an intermediary material, anodized or coated titanium (pink or gold colors) (Fig. 1.12) produce less graying of the soft tissue than the uncoated metals. This process can be performed by the manufacturer, the laboratory, or in the clinician's office. Wadhwani et al. [14] have described the DIY anodization process in detail. Soft tissue thickness is also a key component to creating or maintaining natural soft tissue color. If gray tissue is present around an implant, the two possible solutions are increasing soft tissue thickness with a graft or replacing the abutment with one of the more aesthetic materials mentioned above.

Challenging cases with high *functional risks* and high *aesthetic demands* require carefully selected solutions that mitigate the potential for failure. When proper

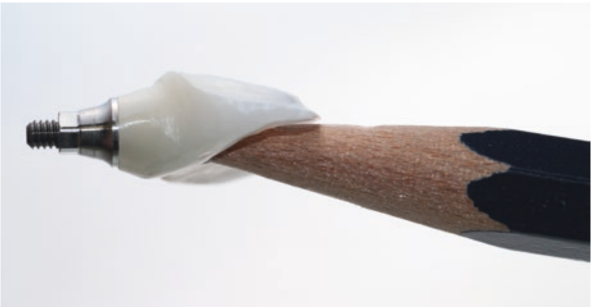

Fig. 1.11 The zirconia framework with Ti Base is an appropriate restoration design for the aesthetic zone with thin tissue biotypes and high smile lines. Here a screw-retained design was utilized

Fig. 1.12 Minor—moderate tissue discoloration can also be mitigated with the anodization of Ti abutments. Here a provisional abutment has to be anodized to have a pink hue in the emergence area and a gold hue in the crown area. This procedure can be easily accomplished in the office with simple materials (see [14])

planning and coordination has been performed prior to starting the treatment, implant selection and orientation can be determined prior to surgery to allow for management of these challenges. For the single-tooth implant in the aesthetic zone, the screw-retained zirconia/Ti Base crown + abutment may prove to be an ideal solution if the implant is able to be placed in an ideal position. See Chap. 15 for Linkevicius and Puisys' excellent review of this treatment option. It needs to be understood though that this restoration requires an attentive technician to ensure that the abutment is as long as possible and it is properly cemented.

Management of the soft tissue around the implant requires interdisciplinary coordination. The surgeon is responsible for creating/maintaining sufficient bone in which to place the implant(s), but also enough bone to properly support the peri-implant tissues. Patient factors (i.e., smoking, diabetes) will also affect the quantity and quality of the bone available. When bone is lost on the roots adjacent to the implant site, it can be very difficult to restore the bone to ideal positions. Soft tissues will generally represent the underlying bone architecture, although grafting procedures may be successful in masking bony defects with increased soft tissue thickness. Thicker soft tissue is less prone to atypical recession and remodeling, thus ensuring better long-term peri-implant aesthetics.

The restoring clinician is responsible for fine-tuning the contours of the soft tissues through the conscientious use of provisional restorations (Fig. 1.13a, b). The final form and position of the soft tissues can be moved (within a range) by changes in the shape of the provisional restoration. Generally, over-contouring of the emergence or pontic will move tissues apically, while flat or under-contoured shapes will allow tissue to move coronally. There are limitations and variables that will affect how much the tissues can be manipulated by the provisional restorations. As a general rule, the soft tissue architecture should be refined in the provisional stage, before making the definitive impression. It is much easier to perform additional surgeries or modify the prostheses in the provisional stage than it is to correct deficiencies after the definitive restoration has been delivered. See Chaps. 10 and 13 for

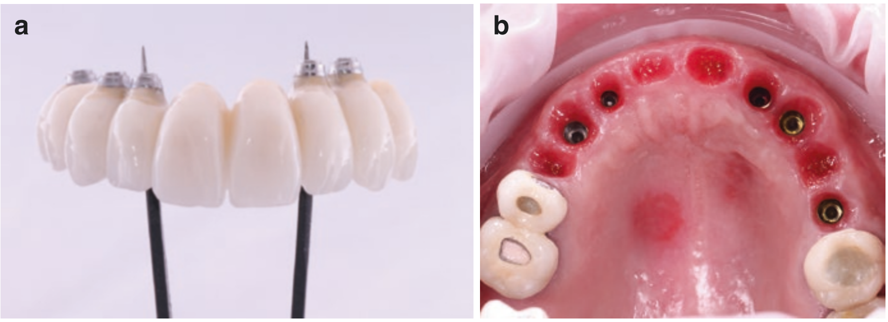

Fig. 1.13 The provisional restoration (**a**) has to be carefully designed with ovate pontics and narrow emergence around the implants in order to shape the soft tissues. (**b**) The tissue contours after 3 months of the provisional in place

more details on the process of fabricating provisional restorations and using them to modify the positions of the soft tissue.

1.4 Surgical Considerations for Treatment Planning Implants in the Aesthetic Zone

The surgical considerations to take into account during the treatment planning by the surgical specialist should mimic that of the restorative concerns and requirements of the restoration in order to provide the best surgical outcomes to support the planned restoration. Therefore, the restorative plan (type of implant restoration, emergence contours, and interproximal contacts) must be known. Otherwise, the surgeon will end up placing the implant where the best available bone dictates it to go rather than the implant restoration dictating the ideal implant position. The surgeon must know specific information concerning the restoration in order to place the implant in the ideal position. This includes the contours of the restoration, the emergence contours, the location of the central fossa, and the method of crown to implant connection.

1.5 Functional Concerns

1.5.1 Occlusion

Implants are designed to withstand heavy occlusal forces vertically. When there are excessive lateral forces, the distribution of forces is limited resulting in bone loss surrounding the implant (Fig. 1.14). Thus, the patient who exhibits grinding habits or bruxism must be placed into a night guard to compensate for the unnatural lateral movement of the jaw, preventing the excessive lateral forces and the excessive bone loss that occurs around the dental implant.

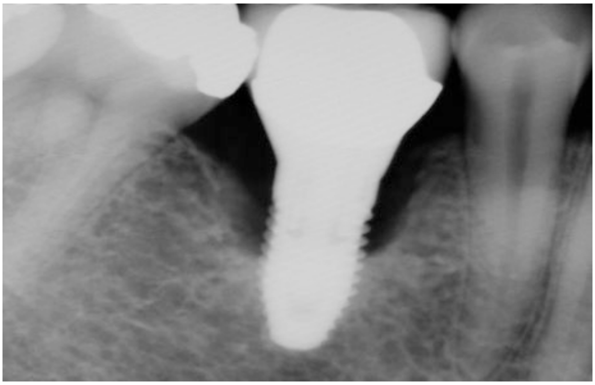

Fig. 1.14 Atypical bone loss around a posterior implant is illustrated in this radiograph. In the absence of any obvious factors, excessive occlusion should be considered as a possible etiology

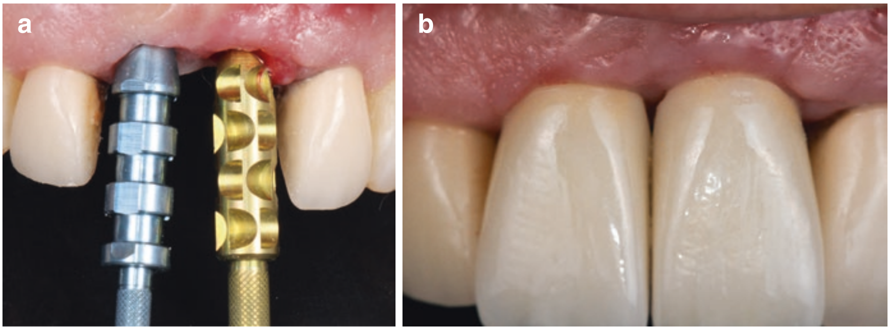

Fig. 1.15 (**a**, **b**) Special care must be used with adjacent implants in the aesthetic zone. These implants are slightly too close to each other and may have exacerbated the deficiency of the mesial papilla

1.5.2 One Versus Two Implants for Two-Teeth Edentulous Space

When the edentulous situation has two consecutively missing teeth, the length of the edentulous space is critical number to determine whether one or two implants will be used to replace the two missing teeth. This is especially critical in the incisor region.

1.5.3 Spacing of Implants

The spacing between implants will be a determining factor for the shape, contours, and volume of the papilla. If implants are too close to each other or to the adjacent tooth, there will be a loss of the papilla (Fig. 1.15a, b). When the implants are too far from each other or the adjacent tooth, the papilla contour flattens (Fig. 1.16a, b). In the posterior quadrant, when this happens food impaction becomes a chronic issue for the patient.

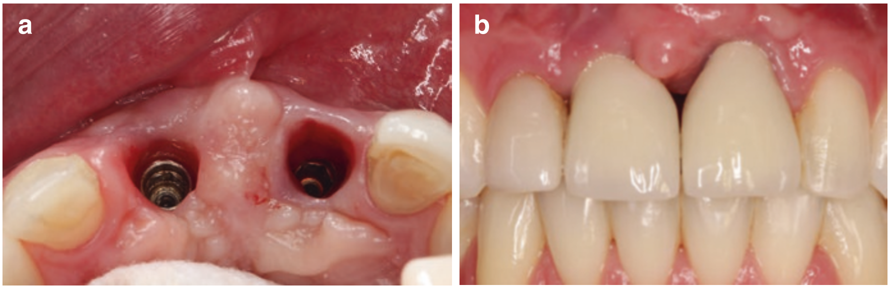

Fig. 1.16 At the other end of the spectrum, these implants (**a**, **b**) are placed too far apart, and this also makes creation of a reasonable papilla challenging at best

1.6 Biologic Concerns

1.6.1 Gingival Biotype [15, 16]

The thickness (real or perceived) of the peri-implant soft tissues should be considered prior to initiating implant treatment. Generally speaking, the thin tissue biotype must be carefully handled intraoperatively, and the use of anodized Ti or zirconia components will need to be considered. The thin biotype is also more susceptible to recession and appropriate remedies need to be planned for should this complication present.

1.6.2 Health of Periodontal Tissue

The periodontal status of the adjacent dentition will have a direct effect on the peri-implant soft tissue.

1.6.3 Future Health of Peri-implant Tissue

The maintenance of the peri-implant gingival tissue health is a concept implant patients must be educated on. The most common reason why the patient is missing a tooth or multiple teeth is due to periodontal disease. If the patient cannot maintain appropriate gingival health around natural dentition, they certainly will have problems maintaining gingival health around implants. This becomes more eminent as the patient ages and manual dexterity becomes an issue due to arthritic changes making it more difficult for the older patient to maintain hygiene around posterior implants. When the implant patient show signs of poor or inadequate oral hygiene home care, the conversion of the implant restoration from fixed to removable must be considered.

1.7 Aesthetic Concerns

1.7.1 Smile Line

The first inspection of the patient requiring an implant in the aesthetic zone is the smile line at rest or repose, half smile, and full smile. This assessment will help to determine facial asymmetries, the amount of gingival show during movements, in full smile, half smile, and at rest. This assessment will help the surgeon determine the critical nature of maintaining tissue volume and contours. Patients with high smile lines should be approached with caution. Any loss of tissue contours or volume with the surgical procedure will be clearly visible resulting in an extremely dissatisfied patient.

1.7.2 UCLA Aesthetic Implant Analysis

This is a simple, inexpensive method to identify deficiencies, discrepancies, and asymmetries with the patient's dentition as well as deficiencies of hard and soft tissues. The analysis requires a clinical photograph of the patient's maxillary anterior dentition with lips retracted. The photograph should show back to the bicuspids with the midline centered in the photograph. (Fig. 1.17) There are three horizontal lines drawn. The superior line, *gingival margin line*, connects the zenith of the gingival margin of the canine to the contralateral canine. The middle line, *mesial papilla line*, connects the mesial papilla of the canine to the contralateral mesial papilla. The inferior line (incisal edge line) is a line drawn from the incisal tip of the canine to the contralateral canine tip. Once the three lines are drawn, any asymmetries, irregularities, and deficiencies are easily detected. This analysis serves as documentation for the clinician to review with the implant patient and to record the clinical condition pre- and posttreatment (Fig. 1.17 and 1.18).

1.7.3 Implant Positioning

In the past, the description of implant positioning has always been stated as three-dimensional (3-D). This concept was formulated due to limited capabilities of the diagnostic tools that were available in the late 1980s and early 1990s with plane film radiography as well as using a freehand surgical approach as a standard to placement of dental implants. The three dimensions or positions that surgeons are

Fig. 1.17 This is the UCLA Aesthetic Implant analysis in use. A, is the *gingival margin line* connecting the gingival zeniths of the canines. B, the *mesial papilla line* connects the papilla mesial to the canines. C, The *incisal edge line* connects the cusp tip of the canines. Here, the UCLA Aesthetic Implant analysis is used to quickly gauge for symmetry and proportion following implant placement and restoration of the left canine, with reasonable (but not perfect) results

accustomed to identify when placing an implant are *mesial-distal*, *buccal-lingual/palatal* angulation (Fig. 1.19), and *apical-coronal* (depth) positions (Fig. 1.20). The modern use of digital technology, specifically the cone beam computed tomography (CBCT) scan, permitted the clinician to observe three-dimensional reconstructed views of the patient's hard tissue. Today the clinician may view the hard tissue structures in the axial, coronal, and sagittal views thus enhancing the ability for the surgeon to place the implant in the ideal three-dimensional position. The introduction of software programs to assist in treatment planning introduced a fourth

Fig. 1.18 The pretreatment view of the patient in Fig. 1.17, illustrating a buccal alveolar concavity and significant disproportion of the teeth and soft tissues due to the retained primary left canine

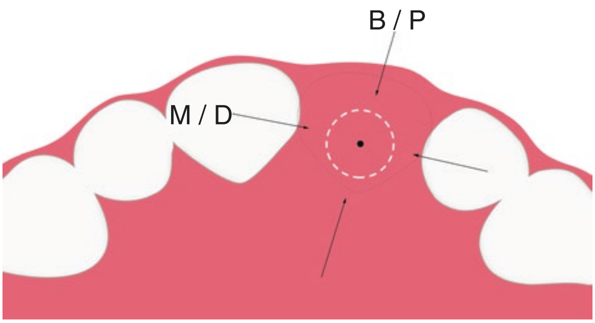

Fig. 1.19 The first two axes of the five-dimensional implant placement consideration. This figure represents both the mesial-distal and buccal-palatal position of the osteotomy

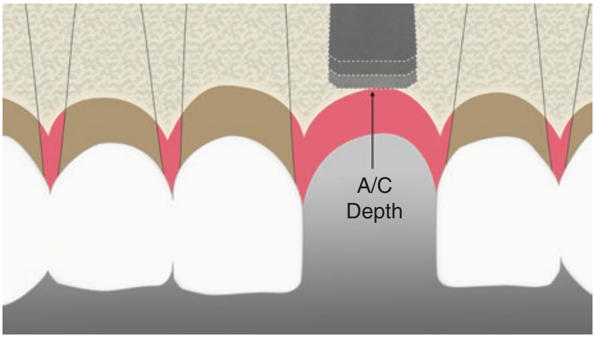

Fig. 1.20 The third axis is apical-coronal depth. This dimension is the depth to which the osteotomy is drilled and the implant placed relative to the planned gingival zenith

dimension to consider. This fourth dimension is known as "arch" position. Depending on the location of the implant in the arch and whether the arch is the maxilla or mandible, the tilt of the implant will differ. For example, an implant placed in the mandibular first molar position must be placed with the axis of the implant tilted slightly to the lingual. This differs from buccal-lingual angulation because accounting for this angulation is necessary to bring the access opening for a screw-retained restoration to come through the central fossa of the restoration. The arch position tilt accounts for the coronal shape of the restoration. The arch position assures the proper relationship of the working cusps of the maxillary and mandibular arches (Fig. 1.21). This fourth dimension becomes even more obvious when dealing with the fully edentulous arch. As the implant positions change from anterior to posterior in the mandible, the lingual tilt becomes more pronounced. If the surgeon attempt to place implants parallel to each other, the malposition of the posterior implants will be noticeable. As the surgical approaches for implant placement transitions from freehand to guided (CBCT planning programs) to navigation (dynamic guided), a fifth dimension became obvious. As the surgeon begins preparing the implant site using navigation approach, the focus is on placement of the drill tip on the cross hair image on the computer screen. Following this cross hair to depth represents the apical tip of the implant. Once the drill goes through the cortical layer on the crest of the ridge, the surgeon's focus is on the outer ring on the computer screen. This is seen as the angular deviation and represents the body of the implant and, ultimately, the neck of the implant located at the crest when the implant is completely seated (Fig. 1.22). This is called the "cone" position. The focus as the drilling preparation of the implant site proceeds, the surgeon attempts to keep the angular deviation as low as possible. Even with the deviation below one degree (1°), the neck position of the implant will have a variance that will change the access opening of the implant. As the technology and instrumentation improves, the surgeon must adapt to the use of the advancing technologies to ideally position the implants accounting for all five dimensions.

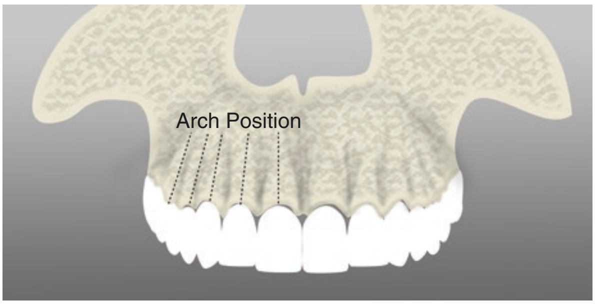

Fig. 1.21 The fourth axis is the *arch position*. This is to take into consideration the angulation of the jaw as we move around the arch. In the maxilla, it forms a somewhat cone shape, with the apical end of the implant being tipped palatally, while in the mandible it is generally the opposite due to the lingual concavity. Cross-sectional CBCT slices will aid the clinician in determining the appropriate angulation for the given patient

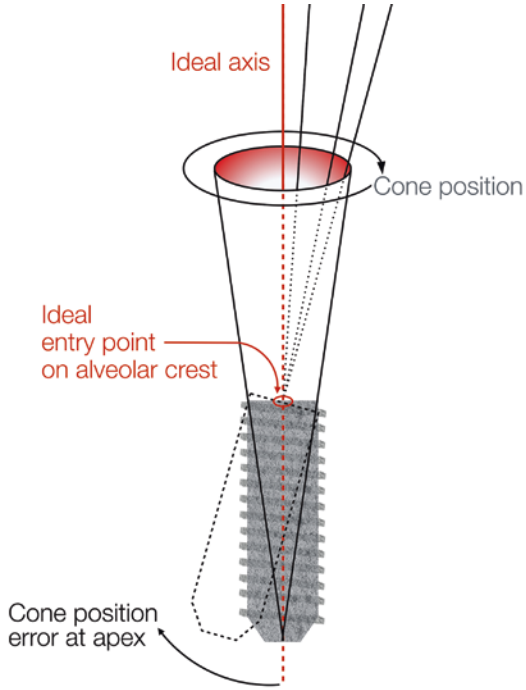

Fig. 1.22 The final axis is the *cone position*. This is to account for the rotational cone within which the surgeon is operating inside the guide or with the aid of navigation. Careful attention must be paid to this axis to ensure that the apical extent of the osteotomy/implant is properly positioned as well as having a significant effect on the exit of the screw channel within the prosthesis

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Radiographic Assessment for Implants in the Aesthetic Zone

2

Mohammed A. Husain and Sotirios Tetradis

Abstract

This chapter reviews the 2D and 3D imaging modalities available to the dental practitioner planning implants in the aesthetic zone while focusing on the unique advantages of cone-beam computed tomography (CBCT). An overview of the basic principles and technical parameters of CBCT technology is reviewed in order to offer guidelines for maximizing image quality. A systematic methodology for CBCT evaluation is then introduced to ensure comprehensive evaluation of the imaged volume while emphasizing the important anatomic considerations at the dental implant recipient site. The most common anatomic variants and osseous pathology encountered in the aesthetic zone are surveyed, with special regard to implications for dental implant therapy. Finally, in silico treatment planning and guided surgery are introduced as CBCT-based tools to enhance the likelihood of a successful surgical and prosthetic outcome.

2.1 Introduction

Radiography is an essential diagnostic tool in the pre- and postoperative assessment for implants in the aesthetic zone. Before the clinician proceeds with implant placement, information about the morphology, volume, and orientation of the alveolar ridge must be obtained. Additionally, the area must be evaluated for the proximity of vital structures, the presence of anatomic variants, and the absence of pathology. To this end, several imaging options are available to the clinician. These options include traditional plain-film radiography, such as periapical and panoramic

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radiographs, as well as advanced, cross-sectional, imaging modalities such as computed tomography (CT) and cone-beam computed tomography (CBCT). Each of these imaging modalities has strengths and limitations to be considered when prescribing appropriate imaging of the aesthetic zone. In many cases, combinations of plain-film and cross-sectional radiography are required for optimal assessment of the area of interest [1]. This chapter discusses common radiographic examinations, especially CBCT, for the preoperative planning and postoperative evaluation of implants in the aesthetic zone.

2.2 Periapical Radiographs

Periapical radiographs are a useful screening tool for the initial assessment of an edentulous site [2]. These radiographs are easy to acquire, deliver a low dose to the patient, and offer the highest resolution of any dental radiograph, higher even than 3D imaging modalities like CBCT [2, 3]. They provide a good overall assessment of the density and architecture of the alveolar bone at the edentulous site and depict adjacent teeth with exquisite detail (Fig. 2.1). Interpretation of these radiographs tends to be relatively straightforward, since the anatomy depicted is familiar to all dental practitioners. The relative absence of metallic artifacts on periapical radiographs makes them especially useful for intraoperative and postoperative implant evaluation.

Periapical radiographs, however, are limited in three key ways. The radiographs offer a small area of anatomic coverage, generally about the area of three teeth [4]. As a result, important vital structures outside the dentate area, such as the mandibular canal and sinus floor, may not be depicted. There is susceptibility to distortion (elongation or foreshortening) from changes in the angulation of the X-ray beam, thus limiting the reliability of linear measurements. This is especially pertinent for edentulous areas due to the difficulty in maintaining parallelism of the X-ray beam and detector in the absence of teeth [1]. Finally, periapical radiographs can at best be accurate 2D representations of the three-dimensional structures and therefore cannot offer diagnostic information regarding the buccolingual dimension of the alveolar ridge [5]. Additionally, the orientation of the alveolar ridge in 3D space and the possibility of buccal or lingual undercuts, for example, cannot be assessed.

2.3 Panoramic Radiographs

Panoramic radiography is among the most commonly used extraoral imaging modalities in dentistry and is useful in the initial diagnostic phase of implant planning. Probably the biggest strength of the panoramic radiograph is its broad area of anatomic coverage that includes both the maxilla and mandible in a single projectional image. The practitioner can relatively easily appreciate the relationship of the

Fig. 2.1 Periapical radiograph at the area of the root tip of #7. The tooth demonstrates evidence of prior endodontic treatment and a widened apical PDL space. Note also the mild periodontal bone loss and generalized normal trabecular architecture

dental arches; the proximity of important anatomical structures such as the maxillary sinuses, nasopalatine, and mandibular canals; and the presence of pathology not readily apparent on intraoral radiographs. Additionally, the panoramic radiograph allows for quick assessment of maxillary sinus volume and the extent of pneumatization of the alveolar ridge. All of this information is obtained at a relatively low radiation dose to the patient.

There are a number of important limitations, however, of the panoramic radiograph. Most important perhaps is the variable magnification within the panoramic image that limits the accuracy and reliability of vertical and horizontal measurements [1, 2, 4, 6, 7]. Other limitations include the extent of anatomical superimposition that is present on the radiograph, and the limited resolution of the image. Like periapical radiographs, panoramic radiographs are 2D images in which buccolingual assessments of the alveolar ridge cannot be made. Unique to panoramic radiographs also is superimposition of a host of adjacent maxillofacial structures onto the dentoalveolar region. In the anterior maxilla, it is common to see superimposition of

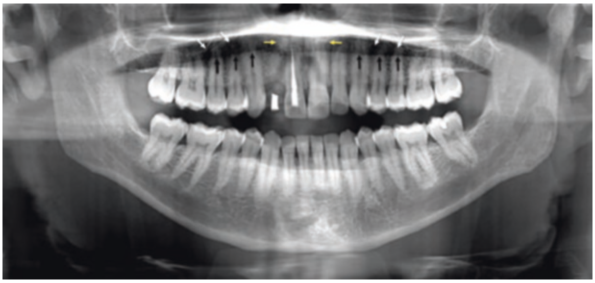

Fig. 2.2 Panoramic radiograph taken for the initial evaluation of the edentulous space at the site of missing tooth #7. Note the extent of superimposition of adjacent anatomic structures. Superimposition of the soft tissue of the nose (*colored arrows*), dorsum of the tongue (*black arrows*), and the oral airway space (*white arrows*) are indicated

the soft tissue of the nose, dorsum of the tongue, and upper cervical spine (Fig. 2.2). In some cases, the oral airway space is superimposed and may be observed as a broad radiolucent area over the roots of the maxillary teeth. This occurs when the patient's tongue is not raised to the hard palate during scanning acquisition. In the anterior mandible, superimposition of the cervical vertebrae can complicate assessment of the alveolar bone. An additional challenge during panoramic radiography is the narrow focal trough in the anterior region, since anatomic structures falling outside of it are distorted. These inherent limitations of panoramic radiography make it insufficient for comprehensive dental implant site assessment [1, 2].

2.4 Cross-Sectional Imaging

Cross-sectional imaging refers to those imaging modalities which produce multiple, thin, contiguous sectional images in axial, coronal, or sagittal planes (Fig. 2.3). Computed tomography (CT) and cone-beam computed tomography (CBCT) are examples of cross-sectional imaging modalities used to varying degrees in dentistry. The main advantages of cross-sectional imaging, and in particular CT imaging, are direct 3D visualization of anatomic structures free of superimposition and the reliability of linear measurements made from CT-generated cross sections [8]. These features allow for optimal assessment of the alveolar ridge for the purposes of implant planning [1]. It is for these reasons that cross-sectional imaging is recommended by the American Academy of Oral and Maxillofacial Radiology (AAOMR) prior to implant placement anywhere in the jaws, including the aesthetic zone [1]. Of the cross-sectional imaging modalities available, CBCT is generally acknowledged to be best adapted for dental imaging due to its relatively low radiation dose, high spatial resolution, and adjustable field of view (FOV) [9]. For a broad comparative evaluation of dental implant imaging modalities, see Table 2.1.

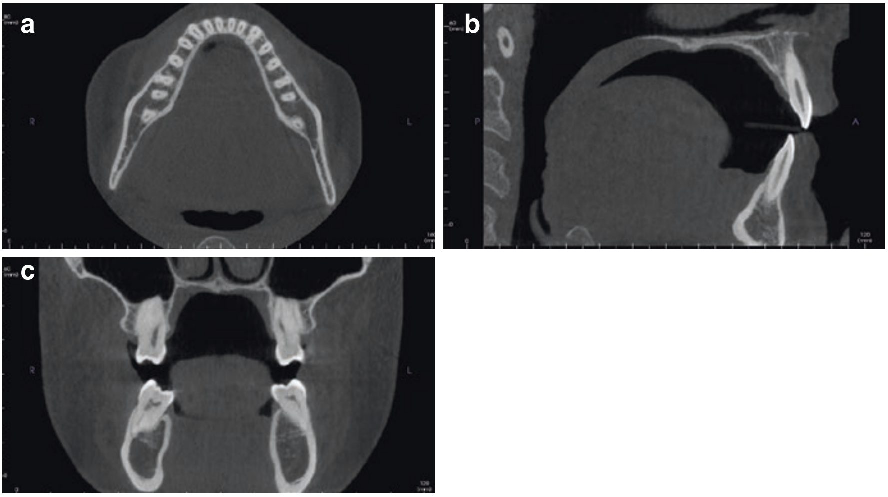

Fig. 2.3 Cone-beam computed tomography images in the multiplanar view (MPR), obtained using a medium field of view. (**a**) Axial view showing the mandibular arch. (**b**) Sagittal view showing the central incisors. (**c**) Coronal view in the area of the molar teeth

Table 2.1 Comparison of radiographic modalities for implant imaging

Imaging modality	Advantages	Disadvantages
Periapical radiography	High resolution, accessible, low radiation exposure, inexpensive	Limited anatomic coverage, 2D, susceptibility to distortion
Panoramic radiography	Broad anatomic coverage, low radiation exposure, inexpensive	2D representation of anatomy, unequal and unpredictable magnification, low resolution
Cone-beam computed tomography	Accurate 3D representation of anatomy, reliable linear measurements, good resolution	Less accessible, expensive, higher radiation dose than 2D

2.5 Principles of CBCT Imaging

At their core, CBCT machines consist of an X-ray source and detector mounted on a rotating gantry. During the scanning acquisition process, the X-ray source and receptor rotate around the object of interest (patient's head, or a specific area of the dental arch), making a partial or full revolution (180–360° arc). The X-ray source emits a pulsatile cone-shaped beam of radiation toward the patient as it rotates. The beam is attenuated by the patient's tissues and is recorded by the detector. Given the pulsatile nature of the cone beam, what is recorded by the detector is in fact a series of 2D projectional images, known as basis images. A typical CBCT scan may expose approximately 300 basis images, each of which may be likened to an oblique skull projection obtained at a slightly different angulation [10]. After the scan has been completed, a reconstructive process ensues in which the raw data of these images are transformed using elaborate computer algorithms to create a three-dimensional map or volume of the region of interest (ROI) [11]. The volume created by this iterative reconstructive process can then be visualized in a variety of ways to assess the area of interest. Scrolling through individual slices in three orthogonal planes, the axial, coronal, and sagittal, is the simplest approach. Curved "panoramic" sections, cross sections, and multiple ways for 3D renderings offer a variety of options to optimally evaluate the various structures. This interaction and manipulation of the 3D volume is typically done in the manufacturer's proprietary viewing software or any other third-party DICOM viewing software.

2.6 CBCT Scanners

There are currently several CBCT scanners on the market manufactured by at least 20 companies [12]. The CBCT machines are distinguished primarily by fields of view (FOV) available, minimum voxel size (similar to a 3D pixel), and patient positioning. The fields of view available for the various CBCT machines vary widely, and although categorizations are made into small, medium, and large fields of view, there is considerable overlap among these three categories. It is generally understood that small FOV scans capture a portion of the dental arch (<8 cm), medium FOV scans capture both dentoalveolar arches in their entirety (8–15 cm), and large FOV scans (>15 cm) capture the maxillofacial structures in addition to the jaws [9]. Some CBCT machines offer a single fixed field of view, while others offer a limited or more expansive range. Those that offer a wider range are generally more expensive. For the purposes of implant planning, units that offer small and/or medium FOV are generally adequate.

Voxel size is another consideration when comparing CBCT units, since smaller voxel sizes contribute to higher resolution images. It is important to note that higher resolution does not necessarily mean a better image, since the small voxel size reduces the signal-to-noise ratio during scan acquisition. A method to improve signal-to-noise ratio is to increase the patient's exposure. While higher-resolution images are generally advantageous, implant planning is not a high-resolution task, so selecting a CBCT unit with the absolute lowest voxel size is not the most important factor.

Patient positioning in different CBCT units can vary significantly. Patients may be imaged standing, sitting, or supine. These variations have implications for handicap accessibility, which may be an important consideration in clinical practice.

2.7 Radiation Dose

Radiation doses from CBCT scans are typically a fraction of conventional MDCT scans, but higher than most 2D radiographic exams, such as lateral cephalometric radiographs, panoramic radiographs, and bitewing examinations [13]. The radiation dose from a CBCT exam can vary considerably, based on the field of view of the scan being acquired and on the specific CBCT unit being used. An approximate median value for a small FOV CBCT scan is approximately 47 microSieverts (μSv); a medium FOV CBCT scan, 98 μSv; and a large CBCT scan, 117 μSv. These values are well within the range of a full mouth set of intraoral radiographs, which deliver approximately 170 μSv of radiation [14]. For a list of effective doses from common radiographic examinations, see Table 2.2.

2.8 Protocol Optimization

Most CBCT units have a number of technical parameters that can be altered by the user. These include parameters related to X-ray exposure, FOV, and the number of basis projections. Optimizing these technical parameters is important to minimize patient radiation exposure and to maximize image quality (Table 2.3). The most important technical parameter that should be adjusted for each CBCT exam is the FOV. Small FOV CBCT scans, in general, yield higher-resolution images and deliver a lower radiation dose to the patient compared to larger FOV scans [9]. For this reason, smaller FOV scans should be preferred when they provide adequate anatomic coverage of the region of interest. For imaging in the aesthetic zone, small FOV (<8 cm) scans generally provide optimal anatomic coverage, although medium FOV scans may be used (8–15 cm) if visualization of both alveolar arches is desired.

X-ray exposure parameters may also be altered from patient to patient and relate to the X-ray tube voltage (kVp) and tube current (mA). Adjusting these parameters

Table 2.2 Effective radiation dose from common dental and medical radiographic exams[a]

Radiographic exam	Effective dose (uSv)	Equivalent days of background radiation
Panoramic	20	2
Full mouth series	177	21
Lateral cephalometric	5	1
CBCT (small FOV <8 cm)	47	6
CBCT (medium FOV 8–15 cm)	98	12
CBCT (large FOV >15 cm)	117	14
Chest X-rays (PA and lateral views)[b]	100	12
MDCT, maxillofacial w/o contrast	913	109
MDCT, abdomen[b]	8000	958

[a]Note: Adapted from Mallya, SM (2016) Principles of cone beam computed tomography. In: Fayad, M Johnson, B (eds) 3D Imaging in Endodontics. Springer
[b]Source*:* Mettler, F., et al. (2008) Effective doses in radiology and diagnostic nuclear medicine: a catalog. Radiology

Table 2.3 Three ways to optimize CBCT imaging protocol

1.	Choose the smallest FOV appropriate for the imaging task
2.	Adjust X-ray exposure parameters for children and large adults
3.	Consider high-speed modes for patients prone to movement

is important given the variation in size and density of patients, particularly for pediatric patients who are most sensitive to the effects of ionizing radiation. However, not every CBCT unit allows for the user to alter these parameters. Most often, the parameters are indirectly altered by selecting preset pediatric, adult, or large adult settings prior to exposure.

Most CBCT units offer high-speed ("quick-scan") and high-res modes. Both modes operate by adjusting the number of basis projections obtained during scanning acquisition [9]. High-speed modes take fewer basis projections, while high-res modes take additional basis projections relative to the standard mode. Obtaining fewer basis projections, in high-speed mode, results in a faster scan, with a lower radiation dose but with inferior image quality. The opposite is true for a high-res scan. The additional basis projections result in a longer scan, with a higher radiation dose and superior image quality. High-speed mode should be considered for patients who are prone to movement and young children. High-res modes are generally unnecessary for implant imaging and further increase the probability of patient movement, often nullifying any gain in image quality.

2.9 CBCT Interpretation

The practitioner who has obtained the CBCT scan has the responsibility to review the entire imaged volume to confirm the presence or absence of disease [15]. Alternatively, the scan can be sent to an oral and maxillofacial radiologist for evaluation. Assessment of CBCT scans should follow a systematic approach to maximize the diagnostic yield from the radiographic examination and to ensure that abnormalities outside the immediate area of interest are not overlooked (Table 2.4). This is best accomplished by beginning the CBCT evaluation in the multiplanar (MPR) view. In this view, one will see cross-sectional images in three orthogonal planes: axial, coronal, and sagittal. The axial slices represent a series of transverse or horizontal sections through the imaged volume, the coronal a series of contiguous frontal sections, and the sagittal a series of lateral sections. It is best practice not to begin in the area of immediate interest, to reduce the likelihood of missing incidental pathology. Rather, one should begin at the superior edge of the imaged volume in the axial view and scroll to the inferior edge. Next, move through the sagittal slices from lateral edge to lateral edge, and finally in the coronal slices from the anterior

Table 2.4 Key steps in CBCT interpretation

1. Scroll through all axial, coronal, and sagittal slices
2. Note any abnormal findings, using natural anatomic symmetry as a guide
3. Observe suspected areas in all cross-sectional planes
4. Categorize finding as anatomic variant, physiologic calcification, or potential pathology
5. Determine whether finding will require follow-up, and if so, with radiographs, referral, or biopsy
6. Document
7. Proceed to area of immediate clinical interest

end of the volume to the posterior. While scrolling through the volume, a good understanding of the anatomy of the imaged field is necessary to detect abnormalities. Nonetheless, the natural anatomic symmetry of the patient, in many instances, can be used as a guide for this purpose. When an abnormality is identified, it should be viewed in all three planes to best assess its radiographic features. Additional reconstructions could be made to further visualize the area. After thorough visualization of the abnormal area has been performed, the abnormality should be categorized as an anatomic variant, clinically insignificant finding, or potential pathology. Suspected pathologic findings should be documented, differentially diagnosed, and addressed by radiographic follow-up, referral, and/or biopsy. If questions regarding the proper interpretation of the CBCT scan arise, referral to an oral and maxillofacial radiologist should be considered. After reviewing the entire volume, it is then appropriate to focus on the area of immediate interest.

The 3D volume rendering view is an attractive feature of CBCT imaging, sometimes present on the multiplanar view or elsewhere within the viewing software. Caution should be exercised when making diagnostic conclusions from the 3D rendering, since the rendering depicted is generated from an alterable thresholding function. All diagnoses should be based on the planar CBCT cross sections. The 3D views can be used as adjunctive radiographic evidence and are most useful for a broad evaluation of the patient's anatomy. Asymmetries, fractures, and growth alterations of the maxillofacial bones are more easily visualized on the 3D rendering.

2.10 Normal Anatomy of the Aesthetic Zone

Small FOV CBCT scans of the aesthetic zone will generally encompass the alveolar bone in the anterior maxilla and mandible, as well as a portion of the nasal cavity and maxillary sinuses. The alveolar bone in in these areas should demonstrate intact cortices of regular thickness. The trabecular bone should be lacy and relatively uniform in density. The primary vital structure in the anterior maxilla that can influence implant placement is the nasopalatine canal. This canal should be relatively symmetric in shape and houses the nasopalatine nerve, which exits the incisive foramen and supplies the mucosa of the anterior hard palate. In the anterior mandible, the lingual foramen and lingual canal are frequently observed and represent terminal branches of the lingual artery entering the anterior mandible. The diameter of the lingual canal should be noted, as it is a reflection of the blood-carrying capacity of the vessel and, if wide enough, may result in significant bleeding if violated during surgery [16].

Within the area of the nasal cavity and maxillary sinuses, dark airway spaces should be observed. These air spaces can vary significantly between right and left sides, as an anatomic variant. The nasal turbinates will be seen at the inferior aspect of the nasal cavity as soft-tissue density structures and may present quite asymmetrically. This is a normal finding and represents the physiologic process of nasal cycling.

2.11 Five Common Anatomic Variants in the Aesthetic Zone

One of the most common anatomic variants noted in the jaws, which also presents in the aesthetic zone, are areas of idiopathic osteosclerosis (Fig. 2.4a). The prevalence of this finding in the maxilla and mandible is approximately 6%, although there are reports of frequencies as high as 30% [17]. Areas of idiopathic osteosclerosis represent sites of high bone density and present on radiographs as localized, relatively uniform radiopacities and are incidentally detected. Unless extensive, the finding of osteosclerosis would not adversely affect implant placement. However, a resistance to drilling might be expected if the implant is placed through one of these areas due to increased bone density.

Variations in alveolar morphology are a frequent and important anatomic variation for treatment planning of implants in the aesthetic zone. The morphology and volume of the alveolar ridge can vary dramatically among patients. In particular, the

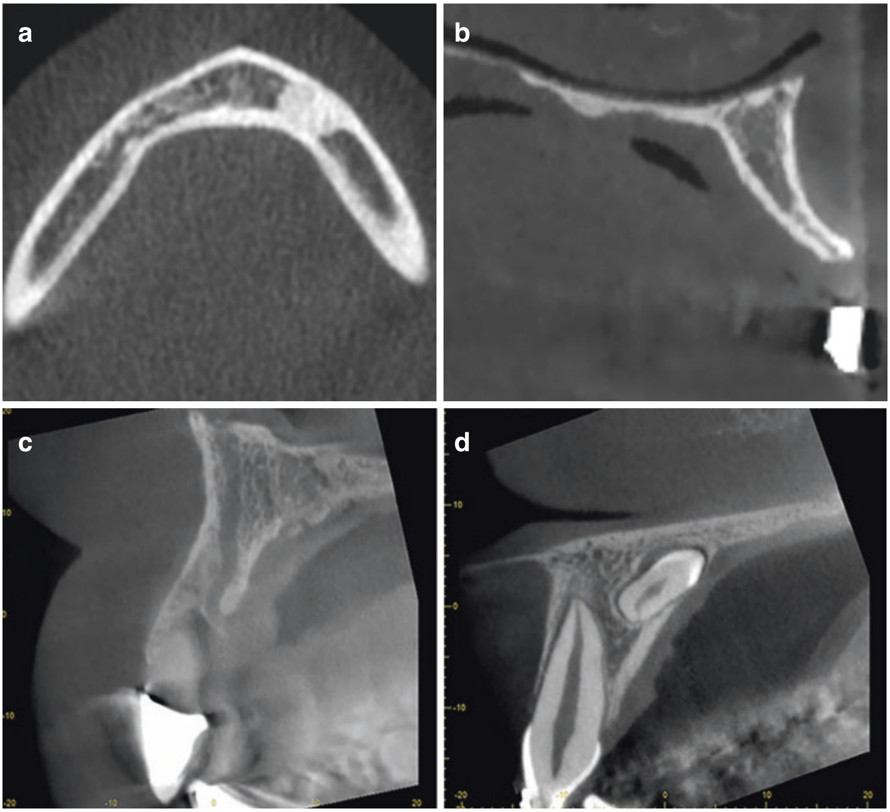

Fig. 2.4 CBCT images of common anatomic variants in the aesthetic zone. (**a**) Osteosclerosis of the left mandible at the canine area. (**b**) A marked buccal concavity at the area of missing tooth #7. (**c**) The canalis sinuosus running through the alveolus palatal tooth #9. (**d**) A mesiodens engaging the hard palate palatal to tooth #8

presence and depth of the buccal undercut, and the angulation of the alveolar ridge, can limit or alter the treatment approach (Fig. 2.4b). In the fully dentate maxillary arch, the buccal undercut tends to be most severe in the area of the maxillary lateral incisors [18]. This is an important anatomic variation to consider to avoid perforation of the buccal cortex, and an unacceptable aesthetic result. Moderate to severe defects of the alveolar ridge are to be expected with previous loss of teeth, previous loss of implants, severe periodontal disease, or trauma. A history of orthodontic treatment has the potential to adversely or positively affect the alveolar dimensions as well.

A neurovascular anatomic variation commonly seen in the aesthetic zone of the maxilla is the canalis sinuosus. This neurovascular canal contains accessory branches of the anterior superior alveolar nerve and artery. On radiographs, it is typically seen originating from the lateral aspect of the nasal fossa, coursing inferiorly through the alveolar ridge palatal to the maxillary lateral incisor and canine (Fig. 2.4c). Presence of canalis sinuosus should be noted during treatment planning, due to the likelihood of increased intraoperative bleeding upon canal violation [19].

Hyperdontia, or the presence of supernumerary teeth, is a relatively common finding in the jaws. Among supernumerary teeth, the mesiodens is most likely to occur in the anterior maxilla. The overall prevalence of the mesiodens is 0.15–1.9% [20]. These teeth are typically microdontic, commonly inverted, and located at the maxillary midline palatal to the roots of the central incisors (Fig. 2.4d). They may interfere with implant placement and are associated with benign pathological conditions, such as dentigerous cysts. Thus, their assessment prior to implant placement is important and may alter the selection and location of implants.

In the anterior mandible, one of the most important anatomic variations to consider during treatment planning is the anterior loop of the mandibular canal. Merely positioning the implant osteotomy site mesial to the mental foramen is not sufficient to avoid mandibular nerve damage during surgery. This is because the mandibular canal commonly courses in an anterior loop before exiting through the mental foramen. The length of the anterior loop is on average 2 mm but can reach lengths of 6 mm or more [21]. The exact location and shape of the anterior loop should be noted prior to surgery in the area.

2.12 Five Common Pathologies in the Aesthetic Zone

Excluding dental caries and periodontal disease, the most common osseous pathology of the jaws is apical periodontitis. Radiographically, this presents as a loss of bone density at the apex of a tooth (PARL) in response to pulpal infection and necrosis. These lesions, while they are small in size, may histologically represent a periapical granuloma or radicular cyst. However, larger lesions of over 1 cm in diameter, demonstrating corticated borders, are more likely to be radicular cysts [22]. Radicular cysts are the most common cystic lesions of the jaws and most frequently located in the anterior maxilla in association with the lateral incisor or

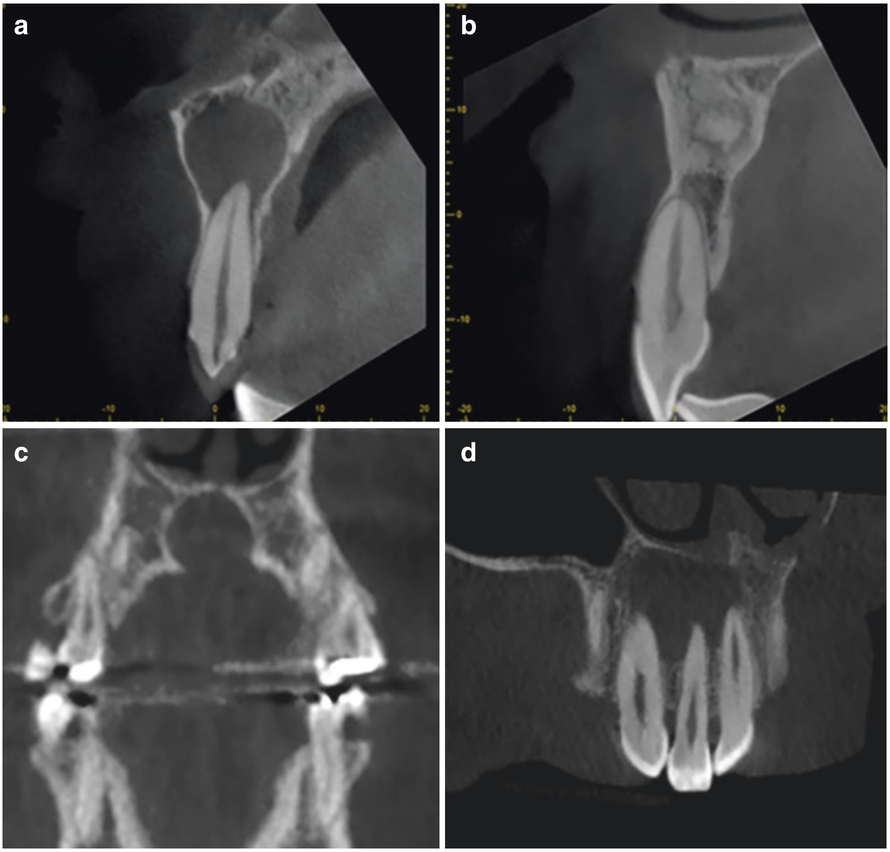

Fig. 2.5 CBCT images of pathologies involving the aesthetic zone. (**a**) Radicular cyst associated with the apex of tooth #7. (**b**) Mixed density periapical cemento-osseous dysplasia superior to the apex of tooth #9. (**c**) Nasopalatine canal duct cyst causing marked expansion of the nasopalatine canal. (**d**) Keratocystic odontogenic tumor scalloping around the apices of teeth #6–8

canine (Fig. 2.5a). Like other benign cysts, they may cause tooth displacement, root resorption, and cortical expansion. Treatment of the radicular cyst typically entails some combination of endodontic therapy, apical surgery, or extraction.

Periapical cemento-osseous dysplasia (PCD) represents the most common dysplasia of the jaws, characterized by a localized change of normal bone architecture. In localized areas, the normal trabecular bone is replaced by a disorganized mixture of fibrous tissue and cementum. This presents radiographically as mixed density areas in close association with the apices of teeth. Most commonly PCD occurs in association with the mandibular incisors, although it can also occur in the anterior maxilla (Fig. 2.5b). Lesions tend to undergo a maturation process over time, from mostly radiolucent to mostly radiopaque. The diagnosis of this entity is radiographically established, and no specific treatment is necessary. From the point of view of dental implants, areas of the jaws affected by PCD have reduced vascularity and therefore thought to have greater susceptibility to infection [23].

The odontoma is a benign, tumor-like malformation, characterized by the production of mature dental tissues: enamel, dentin, and pulp. The odontoma may present as a well-organized bundle of malformed denticles within a soft-tissue capsule (compound odontoma) or, alternatively, as a disorganized mass of dental tissues (complex odontoma.) The compound odontoma most frequently occurs in the anterior maxilla and may cause impaction or malpositioning of the adjacent teeth. The lesions develop during the growth phase, are self-limiting in size, are asymptomatic, and are treated by simple excision [24]. Removal of the odontoma and augmentation prior to implant placement is advised.

The nasopalatine canal duct cyst is a common cystic lesion occurring exclusively in the anterior maxilla and accounts for approximately 10% of the cysts of the jaws [25]. Embryonic epithelial remnants within the nasopalatine canal duct undergo proliferation and cystic degeneration to form the nasopalatine canal cyst. Lesions are very slow-growing and present radiographically as a round- or oval-shaped expansile lesion within the nasopalatine canal (Fig. 2.5c). The lesion may cause tooth displacement or resorption of the maxillary incisors. Patients are typically asymptomatic, although swelling of the anterior hard palate and/or drainage of cystic fluid may occur. If a large incisive canal is seen during radiographic assessment of the anterior maxilla, radiographic follow-up is usually recommended to detect interval growth within the nasopalatine canal, thereby establishing the diagnosis. However, if a definite hydraulic enlargement of the canal, frequently asymmetric, is observed, excisional biopsy of the lesion is recommended.

Benign neoplasms may occur in the aesthetic zone of the maxilla and mandible, though they are most frequent in the posterior mandible. The two most common benign neoplasms of the jaws are the keratocystic odontogenic tumor (KOT) and ameloblastoma. Radiographically, both are corticated, scalloping, radiolucent lesions that can cause significant expansion, tooth displacement, and resorption (Fig. 2.5d). These lesions are distinguished from most other odontogenic cysts of the jaws, by not having an epicenter associated with the crown or apex of a tooth. Incisional or excisional biopsy of suspected neoplastic lesions is recommended. Treatment can range from enucleation to resection of the jaws.

2.13 Radiographic Assessment of the Recipient Site

While the initial pathology review of the CBCT study should be done in the multiplanar (MPR) view, the evaluation of the recipient site is better accomplished on reformatted alveolar cross sections through the area of interest. Most CBCT software has a designated tab or module for the purpose of preoperative implant evaluation (Fig. 2.6). This tab typically consists of a “panoramic” reconstruction, an axial scout slice, and a series of alveolar cross sections. The “panoramic” reconstruction depicted will be derived from an alterable focal trough that is usually depicted on the axial slice. One should ensure that the focal trough follows the maxillary and/or mandibular curvature, in order for the individual cross sections to be perpendicular to the alveolus. This will ensure that the 2D measurements made on the individual

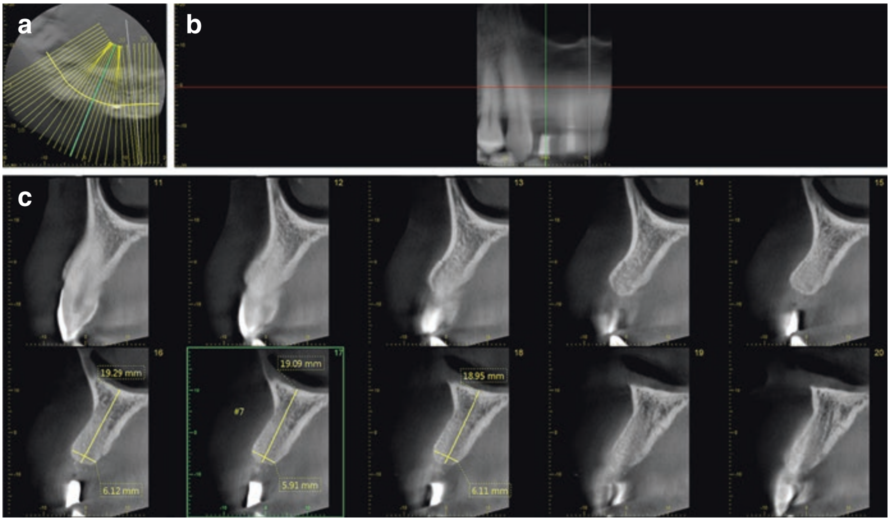

Fig. 2.6 Reformatted CBCT images for implant planning. (**a**) Axial view depicting the focal trough through the maxillary ridge and locations of the orthogonal alveolar cross sections. (**b**) Panoramic reconstruction of the anterior maxilla. (**c**) Alveolar cross sections through the area of teeth #6–8, displaying measurement at the sites of missing tooth #7

cross sections truly reflect intended anatomic assessment. Frequently, a series of lines will be observed perpendicular to the focal trough, designating the locations of the alveolar cross sections. A marking or series of markings may also be seen on the panoramic reconstruction correlating the origin of a selected alveolar cross section to a site on the maxilla or mandible. Users have the option to vary the interval and thickness between successive alveolar cross sections. The interval should be adjusted such that cross sections are visualized through the entire area of interest. Increasing the thickness of the individual slices is a useful strategy to mitigate noise on an image and can allow for better visualization of the mandibular canal. However, the thickness of the slices should generally not exceed 2 mm; otherwise the accuracy of the measurements may be compromised.

One of the primary goals of preoperative implant imaging is a quantitative evaluation of alveolar bone volume in order to choose an appropriately sized implant. Implant selection should maintain adequate space between adjacent implants (3–4 mm), teeth (1.5–2 mm), and buccal and palatal cortical margins (>1 mm) to prevent peri-implant bone loss and cortical dehiscence [26, 27]. When measuring the maxillary alveolus, measurements should extend from the alveolar crest to the base of the alveolus, in the absence of vital structures. Mandibular alveolar measurements begin from the alveolar crest and extend to the superior cortical border of the mandibular canal. The alveolar measurements should be made on successive interval cross sections through the edentulous area. In order to properly orient the alveolar measurements to the position of the final prosthesis, it is imperative that the patient wear a radiographic guide during the CBCT scan. Radiographic guides are typically made of acrylic and formed from diagnostic casts of pre-prosthetic wax-ups at the proposed implant sites. The guide should indicate the proposed angulation of the implant through the crown and the external contours of the crown. The former is important in determining available bone volume at the proposed angulation. The crown contours (in particular the gingival margin of the prosthesis) are critical in determining the ideal depth of the proposed implant. The angulation should be noted with a highly radiopaque material (i.e., barium mixed into composite) placed into the tooth at the proposed implant angulation. The external contours of the tooth can be noted with lead foil applied to the facial surface of the guide. Use of the radiographic guide aids in the localization of linear and angular measurements, increasing precision and alignment of the alveolar ridge with the position of the final prosthesis. The radiographic guide is then converted to a surgical template to guide the osteotomy.

Quantitative measurements of the alveolar bone at the recipient site help to characterize the type and extent of alveolar deficiency. This will guide the decision-making process regarding the necessity and type of bone augmentation procedure required for successful implant placement. Cases with significant alveolar defects will require ridge augmentation as discussed in Part II of this text. When performing ridge augmentation in a delayed approach, additional CBCT imaging after ridge augmentation but prior to implant placement allows the clinician to evaluate the success of the augmentation. The clinician can measure the improved dimensions of the alveolar ridge and confirm successful osseointegration of grafting material (Fig. 2.7). Radiographically, the grafting material should appear to blend in with the adjacent bone, although some types of material may retain a density higher than native bone. If the grafting material is disconnected from the surrounding alveolar bone, failure of integration should be expected. Obtaining this information prior to the implant surgery minimizes intraoperative surprises.

Radiographic evaluation of the recipient site should not simply be limited to measurements of alveolar volume. Several other factors play an important role in predicting the likelihood of a successful outcome. This is especially the case in the presence of an existing tooth. The thickness of the labial cortex adjacent to an existing tooth should be visualized and measured on the CBCT volume, as it is an important prognostic factor of the extent of vertical bone loss and remodeling after extraction. Teeth that are facially positioned in the maxillary alveolus tend to have thin or nonexistent labial cortices (Fig. 2.8) and undergo significantly more vertical and horizontal bone loss upon extraction. For such cases, two-stage implant placement and/or ridge augmentation prior to implant placement should be considered [27]. Dental pathology associated with existing teeth should also be closely assessed on CBCT for its tendency to compromise the adjacent labial cortex. Periapical lesions or periradicular bone loss around the roots of teeth commonly extend to and perforate the labial cortex (Fig. 2.9), increasing the likelihood of vertical bone loss and collapse of gingival architecture upon extraction.

The proximity of adjacent teeth and their levels of bony attachment are important considerations in the predictability of a favorable aesthetic outcome. Both of these features should be closely evaluated on the CBCT volume. Malpositioned adjacent

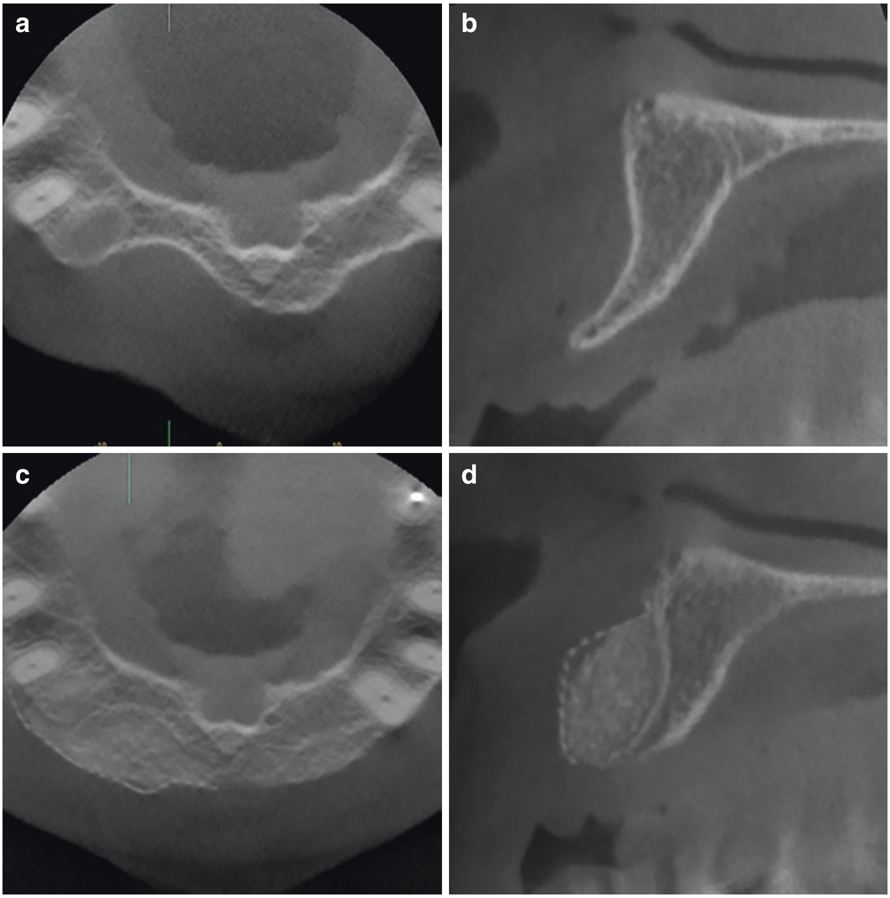

Fig. 2.7 CBCT images pre- and post-lateral ridge augmentation. (**a**, **b**) Axial and sagittal images showing horizontal alveolar deficiency due to a pronounced buccal undercut in the lateral incisor area. (**c**, **d**) Axial and sagittal images after ridge augmentation showing well-adapted grafting material at the buccal aspect of the alveolar ridge supported by a non-resorbable membrane

teeth or teeth with dilacerated roots extending into the edentulous area can compromise ideal implant positioning. In the event that an implant is positioned in close proximity to adjacent roots, there is an increased risk of a lateral resorption and peri-implant bone loss [26, 27]. In such cases, orthodontic repositioning of the malpositioned roots [27], selection of tapered/shortened implants, or alternative implant sites should be considered. Coronal and sagittal cross-sectional CBCT images of the adjacent teeth should also be reconstructed to assess their level of bony attachment (Fig. 2.10). This is because the presence or absence of peri-implant papillae, a critical factor in a successful aesthetic outcome, is directly related to the interproximal bone height of the adjacent teeth [26, 28].

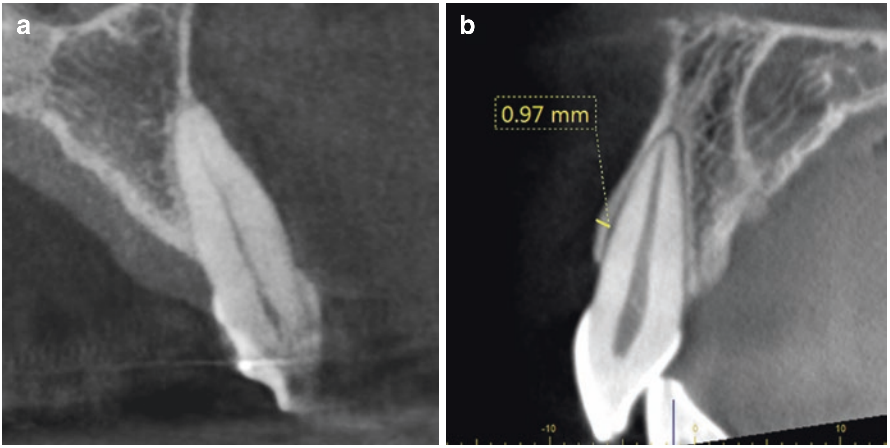

Fig. 2.8 Cross-sectional CBCT images showing marked variation in labial cortical thickness. (**a**) A likely dehiscent labial cortex along the root of tooth #7. (**b**) A thicker labial cortex along the root of tooth #9 measuring approximately 1 mm in the cervical area

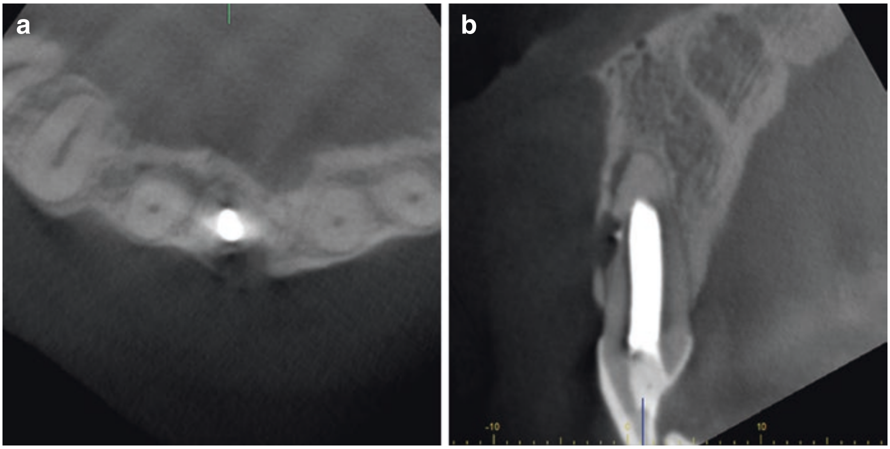

Fig. 2.9 CBCT images depicting external resorption and periradicular bone loss associated with tooth #8 causing a labial cortical defect. (**a**) Axial view and (**b**) cross-sectional view

The quality of trabecular bone at the proposed implant sites should be evaluated on the CBCT volume. At present, this entails a subjective visual evaluation of bone density. For most patients this will be in the average to good range, which indicates a likelihood of successful osseointegration [13]. In some cases, areas of significant trabecular porosity may be visualized, and the absence of a distinct cortication of the mandibular canal. These findings may alter the clinician's treatment approach, especially to avoid potential damage to the mandibular nerve. Quantitative means of

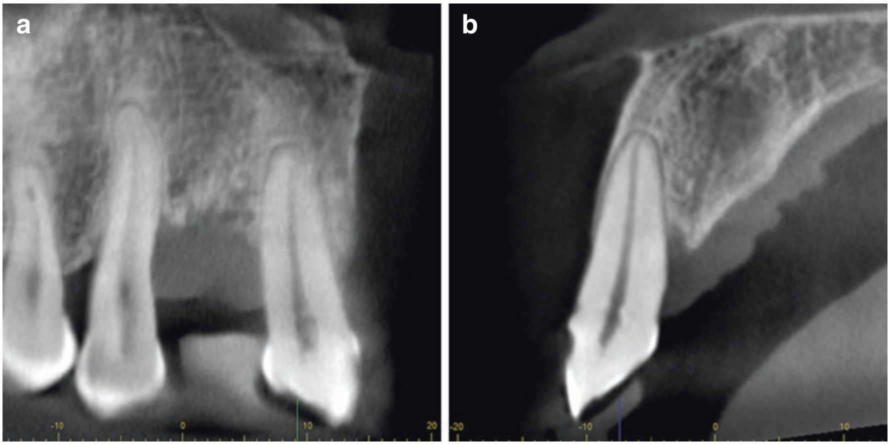

Fig. 2.10 CBCT images of teeth adjacent to the edentulous site of #7 demonstrating marked loss of bony attachment. (**a**) Oblique coronal view and (**b**) cross-sectional view of tooth #8

assessing alveolar bone density, using Hounsfield units, have been explored [29]. In principle, this method seeks to correlate gray values from the CBCT images to relative bone density. However, the variable influence of factors other than object density on the depiction of gray value [9] renders this approach unreliable with dental CBCT units. This is particularly true for small FOV scans [30, 31].

2.14 Virtual Implant Placement

An added advantage of CBCT imaging for preoperative implant planning is the ability to simulate implant placement in silico. Within most CBCT software, the clinician has the ability to select an implant; specify its manufacturer, design, and dimensions; and virtually place it at the desired location in the CBCT volume. The user can manipulate the location of the implant in all three dimensions (M-D, B-L, and S-I), as well as its orientation in space. The implant can be visualized in a 3D rendering view, in addition to standard axial, coronal, and sagittal cross sections. Seeing the implant directly on the reconstructed CBCT volume in full dimensions more easily reveals areas of bone deficiency, as well as the spatial relationships of the implant to the proposed prosthesis and adjacent anatomic structures (Fig. 2.11). This is a useful exercise to confirm the adequacy of the alveolar bone for the proposed implant or can help in determining the need/type of bone grafting, custom abutments, or other alterations to the surgical/restorative plan.

Third-party CBCT software generally have more sophisticated modules for implant simulation. These software are designed to enable the clinician to perform guided implant surgery by faithfully translating an in silico surgical plan to the

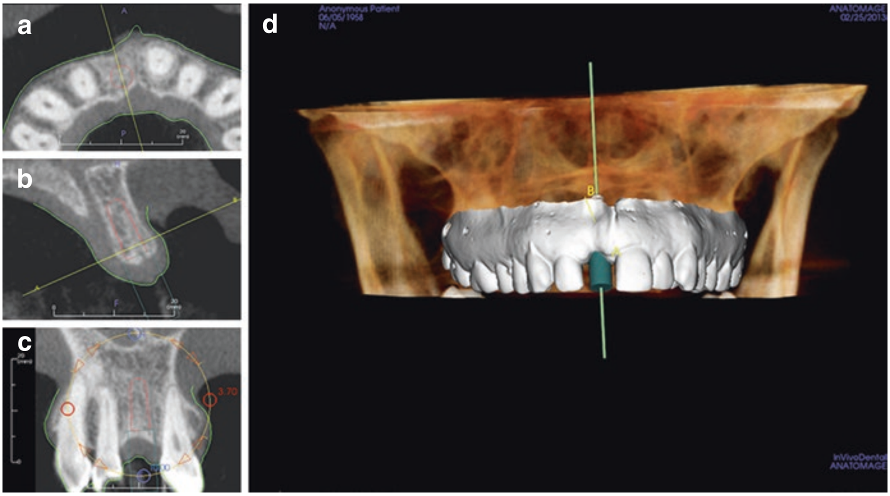

Fig. 2.11 In silico implant placement at the area of missing tooth #8. (**a**–**c**) Axial, sagittal, and cross-sectional views showing the outline of the implant superimposed on the alveolar ridge. (**d**) 3D view showing the orientation of virtual implant #8 relative to the adjacent teeth and maxillofacial structures. Note the fusion of optical scan data with the CBCT volume. (Images courtesy of *Anatomage, Inc.*)

patient via the use of a custom-fabricated surgical template. In order to use such software, one must first export the patient's CBCT data into DICOM format. Every manufacturer's proprietary software has a slightly different method of doing this. DICOM is a universal file format and is the standard for transmitting imaging data in medicine and dentistry. It is distinguished from other file formats in the way that patient identifiers are embedded into the imaging data. Once exported, the DICOM data can then be uploaded into a variety of third-party 3D imaging software for virtual treatment planning.

Guided implant surgery offers the possibility of greater precision and predictability in translating the in silico surgical plan to the patient. In order to successfully create a custom surgical template, additional information regarding the teeth and the mucosa are required. This information can be obtained from an optical scan of a diagnostic cast or directly of the patient. The data from the optical scan is fused with the CBCT volume, which then more precisely depicts the mucosa and contours of teeth, otherwise obscured by artifact. This is an important step because the custom surgical template needs to fit snugly around the teeth and mucosa in order to be effective. Once the virtual treatment plan has been completed, the surgical plan is exported and serves as the basis for the fabrication of the custom surgical template. The guided surgical template is shaped like an orthodontic splint and contains metal sleeves at the proposed implant sites. These sleeves guide the drilling and direction of the implant fixture into the preplanned location and orientation.

2.15 3D Modeling

Dimensionally accurate stereolithographic anatomical models of the mandible or maxilla can be produced from cross-sectional imaging data, including from CBCT scans. This is done by segmenting the bony surfaces of interest from the CBCT data set into a digital 3D surface rendering. The rendering is exported as an STL file printable by a 3D printer. The anatomical models allow for an accurate reproduction of the patient's anatomy, including the course of the mandibular canal, into an object that can be held and directly observed by both clinician and patient (Fig. 2.12). This hands-on inspection of the printed edentulous alveolus can offer a deeper appreciation of the patient's anatomy in challenging cases. For such complex cases, the model can also offer the clinician an opportunity to perform a mock surgery or fabricate custom graft scaffolds prior to actual implant placement. Additionally, patient communication can be facilitated using such a model, in regard to the nature of the implant procedure, the unique challenges presented by the patient's anatomy, and the goals of treatment.

2.16 Intraoperative and Postoperative Assessment

Intraoperative imaging may be utilized to verify proper implant angulation and placement. There also may be a need to visualize the proximity of important anatomic structures. For these purposes, periapical radiographs are preferred, due to their high resolution, ease of acquisition, and low radiation dose. Digital radiographs are particularly advantageous for this purpose due to their near instantaneous display.

Postoperatively, periapical radiographs are the preferred choice for assessment of implant position, peri-implant bone levels, and degree of osseointegration. In asymptomatic patients, a cone-beam CT is generally not required for evaluating

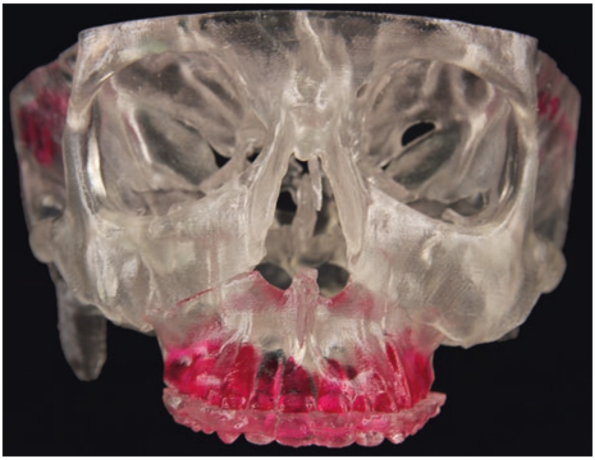

Fig. 2.12 Frontal view of a translucent stereolithographic anatomical model of the maxilla. Note the red coloration of the crowns and roots of the dentition. (Image courtesy of *3D Systems*)

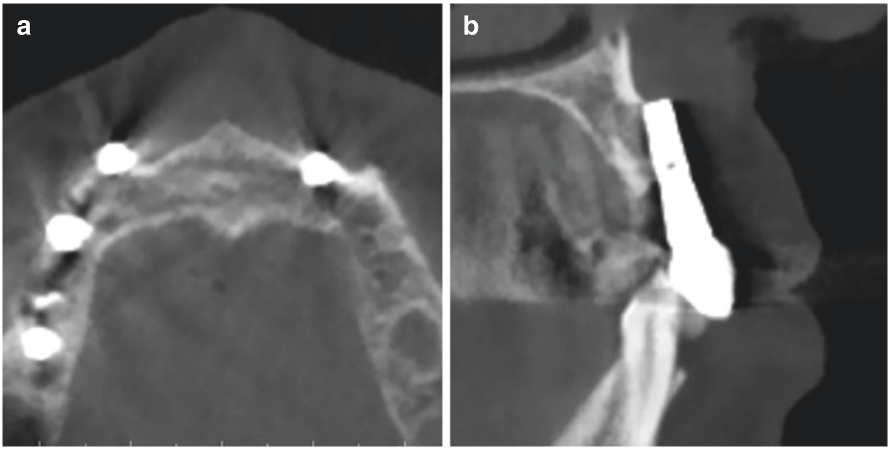

Fig. 2.13 Buccally positioned implants #7 and 10 on CBCT imaging. (**a**) Axial view showing loss of the labial cortex adjacent to both implants. (**b**) Cross-sectional view of implant #7 showing marked buccal positioning and complete dehiscence of the labial cortex

dental implants, due to the pervasiveness of artifacts which obscure peri-implant bone [1]. Of note, radiographic artifacts related to the implant tend to be most evident mesial and distal to the implant fixture. Assessment of the buccal and lingual bone adjacent to the implant is generally more reliable. Atypical loss of peri-implant bone and indistinct osseous contact along the implant are radiographic signs suggestive of failed osseointegration or peri-implantitis.

In cases of postsurgical implant complications, CBCT is an invaluable tool and tends to add important diagnostic information not seen on 2D radiographs. For patients reporting altered sensation postsurgically, CBCT can establish whether an implant is impinging on a neurovascular canal, an important determinant in the decision regarding implant removal. For implants demonstrating immediate postoperative mobility, cone-beam CT imaging can provide information regarding the implant position and, importantly, whether perforation of the cortical plates has occurred (Fig. 2.13) [13].

Conclusion

Radiography is an indispensable diagnostic tool for successful implant planning and treatment. Selecting the appropriate radiographic modality at different stages in the therapeutic process will maximize the diagnostic yield while minimizing radiation dose. CBCT is unique as a dental imaging modality for its ability to offer direct 3D visualization of patient anatomy and precise linear measurements of the recipient site. A disciplined approach to CBCT interpretation and an understanding of normal anatomy are essential to maximizing the diagnostic yield from these radiographs. Virtual implant simulation tools are also available within most CBCT software to allow for a more predictable surgical and prosthetic outcome.

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