Chapter 4
Implant complications associated with two- and three-dimensional diagnostic imaging technologies

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Introduction

The clinical application of dental implants has evolved into a predictable treatment alternative for patients who are missing teeth (1–3). The high success rates have been attributed to specific improvements related to surgical armamentarium, implant design, surface treatments of titanium, the mechanics of the implant-to-abutment connection, prosthetic protocols and associated components, soft- and hard-tissue grafting, immediate and delayed protocols, and soft-tissue management. Concurrent to the progress generated through implant manufacturers and clinical research were significant developments in diagnostic imaging technologies and interactive treatment planning software. Incorporation of evolving technologies will continue to have far-reaching implications on the future of implant reconstruction.

The ability to assess patient anatomy has traditionally been limited to two-dimensional (2D) periapical or panoramic radiography, despite their inherent limitations (4–11). Radiographic distortions or clinical misinterpretation can result in serious complications. These complications can include but are not limited to damage of adjacent teeth; encroachment or perforation of vital structures including the inferior alveolar nerve, the maxillary sinus, the floor of the nose, and the facial or lingual cortical plates (12–25). In addition, implants may be placed in unrestorable positions, implants may fail to integrate owing to faulty diagnosis, implants may be placed too close together, or they may be too wide for the receptor site, resulting in prosthetic and soft-tissue complications.

Standard periapical or panoramic radiographs have been the industry standard in 2D imaging for dental implants since the inception of dental implants and the osseointegration phenomenon. While excellent modalities for detecting dental caries and periodontal disease, there are inherent limitations which can result in complications when assessing dental implant receptor sites, and interpreting spatial relationships of vital anatomic landmarks (26, 27). Two-dimensional periapical and panoramic radiographs cannot accurately inform clinicians of the quality of bone, the density of bone, the thickness of the cortical plates, the width of the alveolar bone, the true proximity to adjacent roots, the inferior alveolar nerve, the mental foramen, and the maxillary sinus. Periapical and panoramic 2D radiographs also contain inherent distortion factors or superimposition of anatomic structures which complicate diagnosis when this distortion is unknown or improperly calibrated. An early study which compared periapical, panoramic, and computed tomographic (CT) scan imaging modalities found significant distortion in conventional 2D imaging, with almost no distortion with medical grade CT (4). In addition, many clinicians fail to calibrate panoramic machines regularly and do not take into consideration the horizontal and vertical distortions that are present (28). Laster concluded that, “Panoramic radiographs should be used with caution in making absolute measurements or relative comparisons. Even when internal fiducial calibration for image distortion of anatomy is used, measurements such as those assessing posterior mandibular facial symmetry may be unreliable” (28). Clinicians who rely solely on 2D imaging technologies may be disappointed in their treatment outcomes.

Three-dimensional (3D) data gathered from CT or cone beam computed tomographic (CBCT) scans of the mandible or maxilla can be extremely revealing. Virtual reconstruction using specific software applications can aid the clinician in evaluating patient-specific anatomy, interpreting bony structures, nerves, vessels, and possible implant receptor sites in relation to the proposed implant placement. The ability to assimilate the information presented by CT-derived data through diagnostic and treatment planning software has the potential to diminish implant complications greatly (8, 26–33).

Case 1: Complications due to scanographic templates

Etiology

To facilitate an understanding of the relationship of the planned restoration to the underlying bone, it has been
recommended that presurgical prosthetic planning commence with the fabrication of a radiopaque scanning template. For a fully edentulous presentation the author believes that a properly constructed scanographic template is an invaluable aid. The template can be fabricated by the dental laboratory technician through the duplication of a diagnostic wax-up, or the patient’s existing denture. The patient will then wear the template at the time the scan is taken. Complications can occur if the template is not properly fabricated or does not fit precisely, leading to movement during the scanning process. In addition, if the patient’s existing denture does not represent the proper tooth position or the wrong plane of occlusion, the location of the subsequently placed implants will be incorrect, even though a CT-derived surgical template may be constructed and utilized. In a study of mandibular positioning to determine whether a correct guiding plane is necessary to position the jaw accurately to the CT scanning plane, Kim et al. concluded that, “Communication among the surgeon, radiologist, and radiologic technician is very important, and it is necessary to have a guiding protocol for implant patient positioning in the CT gantry” (34). Therefore, the surgical template is only as good as the scanning appliance and the final plan. As the author states, “It’s not the SCAN, it’s the PLAN®”.  

Prevention  

The maxillary and mandibular complex can be scanned together if the field of view is large enough. Medical grade CT scans have this ability, as do certain CBCT machines. When contemplating full mouth reconstruction, the ability to scan both arches may be desirable to gain a total overview of the maxillomandibular complex (Fig. 4.1a). The maxillary arch was scanned with a barium

![Fig. 4.1 (a) CBCT scan of a patient with a radiopaque scanning appliance generated from duplication of existing maxillary complete denture. (b) The plane of occlusion was incorrect and off-angle. (c) If this scan appliance were used to plan implants, the resulting restoration would be flawed.](image)
Implant complications associated with two- and three-dimensional diagnostic imaging technologies

sulfate, radiopaque duplicate of the patient’s denture, against the remaining mandibular natural teeth. The right lateral view reveals a flaw in the planning process as it is apparent that the existing maxillary denture’s plane of occlusion was off-angle (Fig. 4.1b). The left lateral view reveals a similar picture of the maxillary denture occluding with the remaining mandibular teeth (Fig. 4.1c). If the implants were planned to coincide with the positioning of the maxillary denture, the resulting reconstruction would be flawed.

Treatment

Fortunately, advanced software applications continue to evolve which can help us to understand the existing occlusal relationships, as well as establish new maxillomandibular relationships. The first step would be to virtually remove the radiopaque maxillary template, and virtually “extract” the natural mandibular dentition (Fig. 4.2a). The maxillomandibular complex can be fully appreciated in Fig. 4.2(b, c). To re-establish a proper plane of occlusion, a virtual wax-up can be created. The virtual tooth position can be superimposed over the radiopaque denture template to appreciate the difference (Fig. 4.3a, b). When the maxillary denture is removed from view the new virtual occlusion can be inspected (Fig. 4.3c). The virtual occlusion can be seen from the left and right lateral sides (Fig. 4.4a, b). While the software applications have advanced virtual methods to re-establish occlusion, the actual implementation of this new maxillomandibular relationship for implant planning is still in its infancy. However, the visualization of the virtual occlusion is useful to understand and determine whether implants can be placed within the envelope of the tooth position (Fig. 4.4c). If implants can be placed, the type of prosthesis can be determined, i.e. fixed-

![Images of dentures and implants]
hybrid, screw-retained or cementable restoration, or an implant-supported overdenture. Currently, there is no substitute for a properly constructed radiopaque scanning prosthesis which represents the ideal tooth position (35–40).

Case 2: Long-term complications due to nerve perforation

A 64-year-old woman presented with pain and swelling in the mandibular left quadrant which was intermittent and associated with vertical movement of the existing full arch fixed prosthesis supported by implants and natural teeth. The panoramic radiograph revealed three remaining natural teeth in the left posterior quadrant each having had root canal therapy and post fabrication to support the left-side reconstruction (Fig. 4.5). The fixed prosthesis was supported on the left side with a universal-type endosseous blade implant, and supported at the midline with a blade implant. The left-side prosthetic design exhibited a posterior molar cantilever, decay around all gingival marginal areas, and radiographic evidence of fractured roots. The surrounding soft tissue was swollen and edematous.

Etiology

Significant dental history revealed that two endosseous blade form implants, one in the posterior right mandible and the other in the mid-symphseal region, had been placed approximately 17 years previously. Subsequently and immediately following the placement of the right-side implant, the patient experienced profound paresthesia of the right lip and cheek area. Over a period of several months the patient was referred to several oral surgeons and neurologists for consultation, and elected not to proceed with further treatment or removal of the offending implant. The cheek numbness resolved 100%; however, a significant area of the lip did not recover. The patient acclimated to the diminished sensory function.
Prevention

As part of the diagnostic work-up a CBCT scan was advised, and performed. The cross-sectional reconstructions of the left blade form implant illustrate the buccal placement within the posterior mandible. The relative density of the buccal and lingual cortical bone, as well as the intermedullary bone, can be inspected (Fig. 4.6a). A significant radiolucent around a great portion of the implant can be evaluated. The mandibular midline cross-sectional slice revealed part of the blade form implant located facial to the ridge and bulk volume of existing bone (Fig. 4.6b). As previously described, there are various vessels (see arrow) that reside in this region which can be visualized and identified through advanced imaging capabilities. The left-side blade form implant was also isolated in the cross-sectional view to reveal buccal placement in relation to the facial-lingual width.
of the mandibular ridge (Fig. 4.6c). The thin facial cortical plate of bone in proximity to the coronal aspect of the implant can be directly visualized and compared with the lingual cortical bone thickness. The natural left and right cuspid tooth roots can be fully appreciated within the body of the mandible through cross-sectional imaging revealing previous root canal therapy and post and core restorations (Fig. 4.6d, e).

Fig. 4.6 The use of cross-sectional images was essential in determining the spatial position of the existing implants and natural teeth (a–e). The contours of the bone, thickness of the cortical plates, and density can be appreciated. An important lingual vessel (arrow) was found in the cross-sectional image at the mandibular midline (c). The natural left and right cuspid tooth roots can be appreciated within the body of the mandible (d, e).
Implant complications associated with two- and three-dimensional diagnostic imaging technologies

The axial reconstructions are important for additional inspection of the mandible from a different vantage point revealing the embedded blade form implant in relation to the residual bone and path of the inferior alveolar nerve (Fig. 4.7). The thin lingual cortical plate is evident. An inspection of the mandibular symphysis reveals the facial position of the embedded blade implant. Using advanced interactive software applications the path of the nerve was accurately traced; however, the integrity of the nerve cannot be determined from these tracings. The path of the inferior nerve, when traced, clearly demonstrates the proximity to the position of the blade form placed in the posterior right mandible. In fact, the blade implant sliced directly through the nerve, causing immediate paresthesia. Returning to the cross-sections, portions of the right blade form implant can be clearly seen penetrating the posterior alveolar bone in sequential slices (Fig. 8a–c). Moving toward the most posterior aspect of the mandible part of the lingual placement of the blade extension avoided that portion of the nerve on the lingual aspect of the mandible (Fig. 4.8d). Unfortunately, the damage had already been done by the anterior extension of the body of the implant.

The reconstructed 3D view of the mandible with the existing fixed prosthesis can be seen in Fig. 4.9(a). Through advanced segmentation techniques the radiopaque ceramometal restorations were modified within the software to appear white, and the mandible’s color was chosen to resemble natural bone as an aid in the process of diagnosis and treatment planning. The ability to segment out the different elements of the patient anatomy allows for unprecedented evaluation. “Selective transparency”, as defined by the author, allows the clinician to choose which element’s opacity will be modified to allow for inspection of the underlying anatomic presentation (41–43). The specific shape of the anterior blade implant with the tell-tale perforations and double abutment head design can be clearly visualized when the outer mandibular cortical bone is rendered semi-transparent (Fig. 4.9b). The side view of the right mandible illustrates the pre-existing long span and the right mental foramen (Fig. 4.10a). Selective transparency further reveals the entire shape of the buried blade form implant, the cuspid root on the right side and, when rotated, the remaining left-side tooth roots (Fig. 4.10b, c). The frontal view reveals the size of the implant which was placed within the midline (Fig. 4.10d). The bone can be removed entirely to reveal the prosthesis, the blade implants, and the path of the bilateral inferior alveolar nerves (Fig. 4.10e). Tracing the canal through the right mandible reveals the path of the nerve (Fig. 4.11a). The blade form implant clearly perforated through the nerve causing permanent paresthesia (Fig. 4.11b). Advanced imaging technologies can aid clinicians in their understanding of how vital anatomy could be injured. The combination of CT/CBCT and interactive treatment planning software provides accurate and essential information which could prevent iatrogenic damage from occurring if used in the preoperative planning.

**Treatment**

After careful evaluation of the 3D data, an appropriate treatment plan was developed to replace the failing ceramometal bridge. The remaining natural teeth and the mobile anterior blade implant had a hopeless prognosis, and would have to be removed. The patient wanted to maintain a fixed-type prosthesis. Using the CBCT scan data, the residual bone was evaluated for potential implant receptor sites. Favorable sites were found in five locations which provided adequate surrounding bone volume to allow for implant fixation. The cross-sectional images reveal five realistic implant simulations placed between the two mental foramina (Fig. 4.12a–e). Once the implant receptor sites have been carefully identified in the cross-sectional images, final confirmations can be made using the 3D reconstruction of the mandible. Using advanced segmentation, the existing tooth roots, blade implants, and prosthesis can be removed to show the implants with the abutment projections in yellow (Fig. 4.13a). The irregular and thin bony topography of the anterior symphysis was found to be unfavorable for implant placement. The ability to section the bone virtually allowed for the anterior mandible to be “leveled” so that the implants could be placed within adequate bone width, while maintaining an even vertical placement (Fig. 4.13b) (44). Further manipulation shows how the implants were placed in a parallel orientation between the two mental foramina and at the same vertical height (Fig. 4.14a). In addition to planning for proper implant placement, the design of the surgical template was

![Fig. 4.7](image_url) The axial view helped to identify the discontinuity of the buccal cortical plate indicating the mental foramina, location of the two implants, and path of the inferior alveolar nerve.
Fig. 4.8 Further investigation of the right-side blade implant revealed the clear perforation of the inferior alveolar nerve which caused long-term paresthesia (a–c). The most posterior aspect of the blade implant extension was found to be lingual to the nerve near the cortical plate (d).

Fig. 4.9 (a) 3D reconstructed images allowing for accurate inspection of the existing fixed restoration and surrounding bone. (b) Selective transparency of various structures is an important tool for inspecting spatial relations.
Implant complications associated with two- and three-dimensional diagnostic imaging technologies

Fig. 4.10 (a) Lateral 3D view revealing the relationship between the existing fixed bridge, the bone topography, and the emergence of the mental nerve. Setting a high level of transparency enables increased visualization of (b) the posterior blade implant; (c) the existing tooth roots; (d) the anterior blade implant; and (e) the enhanced diagnostic quality when the bone is entirely removed. Note the path of the right inferior alveolar nerve.

Fig. 4.11 (a, b) Advanced imaging technologies allow for complete tracing of the right inferior alveolar, revealing the path of perforation which caused paresthesia.
Fig. 4.12 (a–e) Residual bone was evaluated and five favorable receptor sites were found for virtual implant planning of realistic implants, as seen in the cross-sectional images.
Implant complications associated with two- and three-dimensional diagnostic imaging technologies

predetermined. It was elected to use a bone-borne template that would benefit from external screw fixation to prevent movement (Facilitate, AstraTech Dental, Waltham, MA, USA). The fixation screw was planned so as not to interfere with the implant placement, at the midline, while allowing for adequate fixation (Fig. 4.14b).

Using a combination of selective transparencies, all of the elements of the plan were visualized (Fig. 4.15a). Removing the prosthesis reveals the parallel placement of five realistic implants (OsseoSpeed AstraTech Dental, Waltham, MA, USA) of two different color-coded diameters (Fig. 4.15b). Using advanced "clipping" of the 3D axial reconstruction allows inspection of the implant placement, the bilateral nerves, the existing blade implants, and the position of the fixation screw (Fig. 4.16a, b). Once the final positioning has been verified, a surgical template can be virtually fabricated and evaluated (Fig. 4.16c). The CT-derived template constructed based on the virtual plan would allow for accurate drilling and subsequent placement of the five implants. The existing implants and natural teeth were removed, allowing for the tooth-borne template to be seated and fixated, facilitating osteotomy preparation and implant placement through the template (Fig. 4.17).

Fig. 4.13 3D reconstruction of the bone and the five anterior implants with abutment projections (in yellow) and the relationship of the existing bony topography (a) which can be virtually "leveled" to widen the ridge for implant placement (b).

Fig. 4.14 Using advanced segmentation to remove the existing bridge affords improved inspection of (a) the parallel implants, bone width, implant-to-implant distances; and (b) the position of the fixation screw used to stabilize a bone-borne template.

Fig. 4.15 (a, b) Selective transparency revealing the location of the anterior blade implants, two diameters of the virtual root form implants with their abutment projections (yellow).
Dental implant complications

Case 3: Sinus augmentation complications diagnosed by three-dimensional imaging

Etiology
Problems associated with 2D imaging modalities are well documented in the literature and can include inherent distortion factors which can differ with anatomic location, foreshortening, elongation, overlapping of adjacent structures, lack of density determination, no determination of bone width or quality, and poor spatial relationship of vital structures. Despite these limitations for the past two decades the most widely used imaging technology to diagnose, plan, and document postoperative results of sinus augmentation procedures has been 2D periapical or panoramic radiographs (45). These issues alone can lead to complications of inaccurate diagnosis of implant receptor sites and areas which require bone grafting, resulting in unfavorable outcomes.

The postoperative results of a maxillary right-side sinus augmentation procedure can be viewed in the panoramic reconstruction obtained with a CT scan (Fig. 4.18). This 2D image revealed the vertical fill of the bone graft with an indication of the graft’s relative density compared to the contrast of the adjacent structures. The vertical fill of the graft appeared to be sufficient for the placement of adequate length implants. The panoramic image also exhibited a thickness of the Schneiderian membrane evident in the left maxillary sinus. The patient’s prior dental history was significant for a failed implant that had been placed in the posterior maxilla.

Prevention
There are four basic views that can be visualized from 3D CT/CBCT data: the panoramic, the axial (perpendicular to the panoramic), the cross-sectional (perpendicular to the axial), and the 3D reconstructed image. Each individual view modality aids in the diagnosis for that particular plane. It is the author’s contention that for proper planning, all four views must be fully appreciated. The examination of the left maxillary sinus continued with the posterior cross-sectional image, which revealed a small perforation at the alveolar crest and the extent of thickening of the medial and lateral sinus walls (Fig. 4.19a). The nasal cavity and volmer can also be partially appreciated. Moving anteriorly, the cross-sectional...
Implant complications associated with two- and three-dimensional diagnostic imaging technologies

Slice illustrates the apparent invagination of the sinus membrane thickening which occurred from the placement of an implant in this area (Fig. 4.19b). To confirm the positioning of the failed implant, a simulated implant was virtually placed within the sinus (Fig. 4.19c). The length and diameter of the implant were estimated, and it was found to fill the “defect” which was surrounded by inflamed membranous tissue. It can be concluded that the implant was not placed into sound alveolar bone.

**Treatment**

Using interactive treatment planning software, the maxilla was virtually reconstructed as a 3D model. The ability to rotate the maxillary 3D reconstruction freely allows for unparalleled inspection of the sinus/nasal cavity anatomy (Fig. 4.20). Using advanced “clipping” features to slice the 3D model virtually empowers the clinician with software tools to enhance areas of interest (Fig. 4.21a, b). The lack of cortical bone continuity of the floor of the
sinus can be clearly visualized with an enhanced perception of the inner bony contours and volume of the sinus cavity. Further inspection reveals a transverse septum which divides the maxillary left sinus into separate compartments (Fig. 4.21c). A new treatment plan was then developed to fill the left sinus with a new bone graft, and repair the defect in the sinus floor with the anticipation of placing three implants to support a fixed restoration in this posterior segment.

Once the graft had matured, three implants were planned for the right and left sinus augmentation receptor sites, six implants in total. A postoperative CT scan was completed to confirm the placement of the implants. The panoramic reconstruction derived from the CT scan data illustrated the positioning of the six implants within the bilateral grafted sites (Fig. 4.22a). Using the panoramic view, the implant positioning can be assessed within the limitations of this 2D slice. It is apparent that the right-side graft healed with less volume of bone than the left-side graft, which resulted in shorter implants on the right side than on the left side. The question of how much volume should surround each implant may be a matter of clinical philosophy as this can only be assessed through postoperative CT/CBCT scans, a protocol that has not been routinely advocated. The axial image can be useful in determining how the implants were placed in relation to the facial–palatal aspect of the maxillary alveolar ridge (Fig. 4.22b). Implant-to-implant distances can also be fully appreciated in this important view. It can be noted that the implants on the right side appear to be more centrally placed, while the implants on the left side appear to be placed more toward the facial aspect of the alveolar ridge crest. The graft density surrounding the implants and the apparent radiolucent areas in between implants can be appreciated. This radiolucency is often misdiagnosed as bone loss or lack of bone. The black appearance between adjacent implants is a phenomenon known as “beam hardening”, which is a commonly encountered artifact in CT scan imaging. In technical
Implant complications associated with two- and three-dimensional diagnostic imaging technologies

In simple terms, the proximity of the two very opaque metal objects of very high density tends to change the value of the surrounding structures, basically inverting the gray-scale “pixels” from white to black, thus giving the appearance of radiolucency.

Postoperative CT/CBCT images are very important in confirming that implants have been properly positioned in relationship to the newly grafted host bone and the desired prosthetic restoration. A radiopaque scanning appliance worn during the acquisition of the CT scan image helps to provide the link between the underlying bone and the envelope of the tooth to be replaced. The barium sulfate material can be used in differing concentrations (10%–20%) and to highlight either the teeth or the entire prosthesis including the flange area. The scanographic template used for this patient contained 20% barium sulfate to create fully contoured teeth embedded in a clear acrylic base. In addition, to gain direction and angulation, holes were drilled through the occlusal surface. The scanographic template was used as a surgical drilling guide to prepare the osteotomies into the grafted sinus on the maxillary right side. The radiopaque tooth can be seen hovering over the site of an implant placed in the right-side grafted sinus (Fig. 4.23a). The implant was positioned within the bulk of the bone volume, although the apical portion is minimally covered. The 3D reconstruction can be sliced to reveal the inner aspect of the sinus (Fig. 4.23b), which offers a different perspective than the 2D cross-sectional slice. Note that again the implant was well positioned within the volume of the graft and the zone of the “triangle of bone®” (TOB), as originally described in 1992 and first published in 1995 (47–50) (Fig. 4.23c). Therefore, when technology is properly utilized, implant placement can be more accurate and consistent.

For some unknown reason, the surgical guide was not used to prepare the osteotomies for the maxillary left side. The left-side graft placement contained considerably more bone volume and height. However, the most anterior osteotomy was prepared “free-hand” and the implant was placed into the site using a minimally invasive “flapless” surgical approach. Unfortunately, this angulation did not result in the proper placement of the implant. The scanographic template had a guide hole indicating direction for the implant. However, in the postplacement CT scan, the implant can be seen perforating the facial cortical plate (Fig. 4.24a). The apical
position of the implant has been placed into the vestibule, missing the zone of the TOB entirely (Fig. 4.24b). The most distal implant also missed the volume of the bone graft by piercing through the graft as visualized in the panoramic view (Fig. 4.22a). However, the direction of the implant and the lack of bone between the palatal aspect of the implant and the medial wall of the sinus would be impossible to detect without 3D imaging (Fig. 4.25a). Using the 3D clipping functionality allows further inspection of the portion of the implant exposed within the sinus (Fig. 4.25b). The 3D reconstruction of the maxillary left side displays the facial perforation of the anterior implant (Fig. 4.26). The view from above reveals the extent of fill for both the left- and right-side sinus cavities while exposing the perforations of two out of the three implants placed on this side (Fig. 4.27a).

Using advanced segmentation and masking tools, different anatomic structures can be separated from the 3D image, allowing for additional diagnostic insight (Fig. 4.27b). Color can be used to isolate each of the implants and differentiate the sinus graft from the maxilla to increase diagnostic accuracy (Fig. 4.27c).

The segmentation process clearly reveals the anterior implant (magenta colored) perforating the facial plate of bone (Fig. 4.28a). Selective transparency was previously described as the ability to control the opacity for different anatomic 3D volumes which creates a layered effect when using the interactive software application. The use of selective transparency and segmentation of the various entities exposes the position of the implants in proximity to the anterior adjacent teeth. Therefore, by adjusting the levels of transparency the maxilla was made more translucent than the adjacent opaque tooth roots, bone graft, and the three implants, affording unique insight (Fig. 4.28b). This virtual investigation reveals that the anterior implant was positioned through the facial cortical bone, and confirms angulation in close proximity to the adjacent root of the natural bicuspid tooth. The most posterior implant can also be seen as perforating through the sinus grafted bone, leaving threads exposed within the sinus cavity. Slicing laterally through the 3D reconstruction allows further inspection of implant-to-tooth position, implant-to-implant position, and spatial relation of the implants to the graft volume. The distal angulation of the posterior implant can be clearly visualized perforating into the sinus, substantially missing the target area of bone volume (see arrows) (Fig. 4.28c).
Summary of case 3

When the original augmentation procedure was completed for the right maxillary sinus, a postoperative CT scan was taken. The extent of the fill was noted, and it was determined that although it was adequate, the vertical height could have been improved to facilitate the placement of longer implants. Using preoperative CT/CBCT helps clinicians to understand the sinus topography and volume of bone required to fill the cavity to a successful level for long-term integration of the implants.

It appears from the presentation that the left maxillary implant failed because there was insufficient bone support, which may have been undiagnosed at the time. Chappuis stated that, “As implant dentistry is becoming more and more popular among practitioners, and ever more demanding procedures for initial site development in jaws with bony deficiencies are being introduced into daily practice, the displacement of dental implants into the maxillary sinus during implant placement may become a more frequent complication” (51). CT imaging technology offers highly accurate insight for under-
standing why implants or bone grafts fail. The perforation of the alveolar crest was still present, and would not regenerate without surgical intervention (see Fig. 4.19a). When the left maxillary augmentation was completed, and with an appreciation of what had transpired on the right side, enough bone graft material was used to fill the cavity to support longer implants (Fig. 4.22a). The difference in implant lengths can be directly compared for each of the two sides. When it was time to place the implants a surgical guide was used for the right side and not the left side. The volume of bone on the left side was adequate on the facial and the palatal aspects of the implants, but barely covered the apical portion of the implants (Fig. 4.23a). However, this should not be a problem in the long term. The middle implant placed in the maxillary left sinus reveals a good thickness of bone apical to the implant, with good adaptation of the graft to the medial wall of the sinus (Fig. 4.23b, c).

The issue for this case involves two implants placed in the maxillary left sinus. In viewing the panoramic reconstruction in Fig. 4.6(a), the difference in angulation and positioning from the implants on the left versus the right side is readily apparent. However, it is the cross-sectional slices and the 3D reconstruction that are the most revealing. The anterior most implant missed the bone graft entirely. This is clearly not acceptable, and could have been avoided by using a properly constructed surgical guide and/or by raising a flap to visualize the site. While there is a place in implant reconstruction for flapless surgery, in the author’s opinion, this modality should only be attempted when (i) there is a CT/CBCT scan to confirm that there is adequate bone present for integration, (ii) there is an abundance of keratinized tissue, and (ii) a surgical template is used to place the implants within the volume of bone.

Another common contributing factor to malpositioning of implants relates to the construction of the scanographic template. When the template has holes predrilled, they are usually placed within the central fossa of the tooth. The angulation can be arbitrary. When the scan is then taken, and the predrilled hole visualized, often there is an attempt to move the implant so that the abutment will emerge through the hole. If the angulation and positioning of the hole are correct, this can work...
Implant complications associated with two- and three-dimensional diagnostic imaging technologies

If the angulation and positioning of the hole are not ideal, it can lead to placing the implant in the wrong position. The hole drilled through the template in Fig. 4.24(a), if followed, would create an osteotomy and subsequent placement of the implant which would perforate the facial plate, missing the bulk of available bone. Therefore, the proper protocol is to create a full-contour barium sulfate tooth, without predrilled holes, for implant planning. The implant can then be positioned within the TOB, and a simulated abutment projection used as an aid to achieve restoratively driven implant reconstruction. A CT-scan software application derived template can then be used for surgical guidance to ensure positioning within the most volume of available bone. Using this concept a simulated realistic implant 4.5 mm wide by 19 mm long (OsseoSpeed AstraTech Dental) could have been placed to take advantage of the entire bone volume (Fig. 4.29a). A realistic 15° angulated abutment was then placed on the implant to fall within the envelope of the desired tooth position (Fig. 4.29b).

**Case 4: Complications in the mandibular symphysis related to diagnostic imagery**

**Failed implants**

The anterior mandible has often been thought of as one of the safest areas to place implants owing to the assumption that there will always be dense bone anatomy and limited exposure to vital structures. The posterior mandible has a defined lingual concavity, which can be palpated. The anterior mandible can have a conventional shape which is favorable to implant placement, or can be shaped like an hour glass, which would not be conducive to implant placement. Certainly the course of the mandibular canal and potential anterior loops of the mental nerve should be considered for this region, but cannot be consistently or accurately detected with 2D radiography. Implant complications can result from poor planning, poor execution, and a poor understanding of the existing patient anatomy. Therefore, problems can occur when the natural anatomic variations are not fully appreciated. In addition, without 3D imaging and associated tools, the etiology of why complications have occurred may not be recognized.

A female patient presented with what was termed “cluster failures” in the anterior mandible. The referring doctor claimed that the implants were “tainted” in some manner, and thus all failed owing to microscopic surface contamination or machining of the implants. A CT scan was completed for this patient to help determine the cause of the failures, and to determine the next course of treatment. The reconstructed panoramic view reveals two remaining implants of the original seven that were placed in the anterior mandible (Fig. 4.30). The symphysis exhibits several large radiolucent areas where the implants once resided. The extent of the damage can better be appreciated in the axial view (Fig. 4.31a). The inferior border of the mandible anteriorly was intact and demonstrated dense cortical bone anteriorly. Moving...
superiorly, the facial and lingual cortical plates were thin and perforated (see arrows) (Fig. 4.31b). The mental foramina can be seen in this view bilaterally, along with one of the remaining implants. Further investigation of the cross-sectional views revealed a through-and-through perforation of the anterior mandible from facial to lingual, above the dense basal cortical bone of the inferior border (Fig. 4.32a, b).

**Etiology**

The cross-sectional views capturing the position of the right and left remaining implants disclosed perhaps the final clue to discovering the true cause of the failures. The right implant can be seen in Fig. 4.33(a) and the left implant in Fig. 4.33(b). Three-dimensional reconstructions were also completed, and offer additional information regarding the residual mandibular anatomy (Fig. 4.34a, b). The bone destruction was obvious. Even though it is highly unusual for four implants to fail at once, the causative factor was most likely not due to the manufacturing tolerances of the implants. Using the remaining implants as a guide, the cross-sectional images reveal angulations which are inconsistent with implant survival. A simulated implant was placed parallel in the lingual vestibule at the same angle as one of the original implants (Fig. 4.35a). To confirm the angulation, length, and diameter, it was moved directly over the remaining implant (Fig. 4.35b). The simulated implant was next moved to a cross-sectional image where one of the
Implant complications associated with two- and three-dimensional diagnostic imaging technologies

Implants had failed, leaving a large radiolucent defect (Fig. 4.35c). This exercise continued with the axial image allowing for inspection of each of the four radiolucent areas where implants once resided (Fig. 4.36).

Prevention
The 3D reconstruction revealed the anterior mandible with the two remaining implants using the interactive software tools to segment the entities (Fig. 4.37a). A realistic external hex-type implant (yellow) was superimposed over the left implant to mimic its position (Fig. 4.37b). The original implant was then replaced with the new simulated implant to understand better what had caused the implants to fail (Fig. 4.37b).

Treatment
Four additional virtual simulated implants were then created and placed into the anterior mandible at the same angle and position as the original implants as seen in the occlusal view of the 3D reconstruction (Fig. 4.38a).

Fig. 4.31  (a) Axial view revealing the radiolucent areas where the implants failed; (b) full extent of bone destruction amplified through the various slices (see arrows).

Fig. 4.32  (a, b) To investigate the remaining bone further, cross-sectional images revealed a through-and-through perforation above the dense basal cortical bone.
Again, the bone destruction is readily apparent. The lingual view offers an estimation of the original height of the anterior mandible (compared to the right and left remaining implants) (Fig. 4.38b), while revealing the perforations of the lingual cortical plate (Fig. 4.38c). To illustrate the point further, the 3D reconstruction was sliced to show the severe angulation of one of the remaining implants (Fig. 4.39a). The superimposed realistic virtual implant offered additional information about the malpositioned implant (Fig. 4.39b). Moving toward the midline, the extent of the symphyseal defect was noted (Fig. 4.39c). To complete the process, all of the simulated “original” implants were positioned to reflect their angulation when initially placed, resulting in perforation of the lingual cortical plate, eventual failure, and removal. The line-up of the failed implant simulations is seen at the same angulation as the remaining right-side implant which led to lingual perforations (Fig. 4.39c).

**Summary of case 4**

Two-dimensional panoramic radiographs have inherent limitations and cannot reveal the bone density, bone width, or trajectory of the bone. Therefore, if these
Implant complications associated with two- and three-dimensional diagnostic imaging technologies

Fig. 4.35 Following the original angulation of the existing implants, a simulated implant was placed parallel at the same angle (a); and then superimposed over the implant for confirmation (b); and then within the radiolucent area where an implant once resided (c).

Fig. 4.36 Simulated implants as seen in the axial view.

Images are solely used for treatment planning and subsequent placement of dental implants, the results may be catastrophic. Case 4 represented the failure of four implants placed into the anterior symphysis. The failure of one implant is troublesome, but when many implants fail in a manner where bone is destroyed, it is often blamed on factors out of the control of practitioners. The original causative factor was thought to be related to some type of contamination of the implant which would result in cluster failures. Two-dimensional imaging would never have revealed that poor surgical technique was the actual reason for the failures. Using 3D imaging and all of the views afforded by this technology allowed for inspection of the bone post implant failure. The remaining two implants helped to define the original
Dental implant complications

The 3D reconstruction was also a valuable tool in simulating the original placement of the implants, which resulted in perforation of the lingual cortical plate, and subsequent loss of the fixtures.

Placement of implants at unfavorable angles occurs with greater frequency than clinicians, implant manufacturers, and dental laboratories wish to admit. For the mandible, the position of the patient at the time of surgery could be a contributing factor, i.e. lying down or sitting up. The practitioner must be cognizant of the relationship between the inferior border of the mandible, the alveolar crestal bone, and the plane of occlusion.

With the mouth wide open, it may become easy to become disoriented regarding these planes. Surgical templates based on 3D planning can help to minimize the effect of patient positioning, and aid in the drilling sequence and implant placement within the volume of bone, in the best position to support the desired restoration.

Fortunately, none of the malpositioned implants entered vital anatomic structures, which could have resulted in far more urgent complications, including some which may be fatal. It has been reported in the medical/dental literature that implant placement in the anterior mandibular symphysis can perforate vascular vessels, which can lead to profuse bleeding and obstruction of the airway. In a study of human cadavers, Mardinger et al. stated that, “Injury to the vessels in the floor of the mouth is probably more prevalent than reported” (52). They concluded that, “it appears that vessels in the floor of the mouth are sometimes in close proximity to the site of implant placement. Caution should be exercised when placing implants in this area”.

A CT/CBCT scan allows for inspection of the infraforaminal region, where these vessels reside (Fig. 4.40a). Often the lingual artery can be found at the midline of the symphysis and the genial tubercle in cross-section (Fig. 4.40b).
Fig. 4.39 (a–d) 3D cross-sectional slices allowing for superimposition of the realistic implants offering additional information about the original malpositioning.

Fig. 4.40 (a) CT/CBCT scan allowing inspection of the intraforaminal region, which may contain vessels and nerves that should be avoided when placing implants; (b) lingual artery found in the cross-sectional view.
Dental implant complications

If the osteotomy drilling sequence perforates these and other named blood vessels in the region, the sublingual space can fill with blood, which can compromise the airway if it is not immediately determined. Implant surgery near the midline of the mandibular symphysis can be dangerous if these arteries are left undetected (14, 15, 52, 53). Two-dimensional radiography cannot determine these vessels. Therefore, CT/CBCT scans are recommended before implant reconstruction in this anterior mandible.

The path of the inferior alveolar nerve is also difficult to assess with 2D imaging modalities. Two-dimensional panoramic imaging modalities offers a good scout’s view of the maxillary–mandibular complex, but cannot determine the spatial positioning of the inferior alveolar nerve. The use of CT/CBCT imaging allows for a more accurate appreciation of the course of the nerve as it enters the mandible through the lingula, and exits at the mental foramen. The distortion factor of panoramic radiology differs among manufacturers and the time between calibrations, and is not equal around the arch. The oval shape of the head is seen as a flat image, and superimposition of anatomic features occurs. If the distortion factor is unknown, and the actual position of the nerve cannot be determined in the vertical or horizontal plane, complications can occur (Fig. 4.41a). If careful depth control is based on faulty information, perforation of the inferior alveolar nerve can lead to permanent paresthesia (Fig. 4.41b). This unfortunate situation could have been avoided with an understanding of the actual location of this vital anatomic structure through 3D imaging modalities.

Conclusions

Implant dentistry is one of the most predictable treatment alternatives that can be offered to patients who are missing teeth. Predictability and accuracy can be greatly enhanced by thorough presurgical diagnosis and treatment planning. Conventional radiographic imaging modalities such as periapical and panoramic radiographs or digital counterparts are limited by their ability to provide clinicians with only a 2D interpretation of existing hard and soft tissue. In addition, these imaging modalities contain inherent distortion factors which may misrepresent bone topography and/or critical vital anatomy, potential grafting and implant receptor sites. However, as recently as 2001, Dula et al. (6), when reviewing radiographic assessment of implant patients, concluded that; “Panoramic radiography is considered the standard radiographic examination for treatment planning of implant patients, because it imparts a low dose while giving the best radiographic survey. Periapical radiographs are used to elucidate details or to complete the findings obtained from the panoramic radiograph. Other radiographic methods, such as conventional film tomography or computed tomography, are applied only in special circumstances, film tomography being preferred for smaller regions of interest and computed tomography being justified for the complete maxilla or mandible when methods for dose reduction are followed”.

Advances in diagnostic radiologic techniques have dramatically improved with acceptance of CT and CBCT scan technology for dental applications and thus the entire dental implant industry has moved forward.

Fig. 4.41 (a) Cross-sectional view illustrating how an implant perforated the inferior alveolar nerve causing paresthesia due to faulty depth control or lack of diagnosis of the position of the inferior alveolar nerve. (b) The nerve is shown in orange.
(54–58). Clearly, the tide has turned in favor of new, lower dose CBCT modalities which offer the most reliable combination of desired images for proper anatomic assessment, diagnosis, and treatment planning. A comparison of conventional digital panoramic orthopantomograms (OPTs) and digital volumetric tomography (DVT) using CBCT found that, “Panoramic views generated from volume data obtained by using the evaluated DVT prototype are comparable to conventional OPTs regarding their diagnostic quality” (59). Further investigation in a follow-up study concluded that, “Radiation dosages for the investigated 3D CB device are closer to those seen in OPG rather than CT imaging. These circumstances confirm a unique information/radiation dose ratio for CB imaging, possibly justifying its larger scale application in implant dentistry” (60).

This chapter has provided several clinical examples which demonstrated the 3D capability of CT, CBCT, and interactive CT as it applied to practical clinical situations. The enhanced diagnostic range of this evolving technology empowers the clinician with the necessary tools to avoid potential complications associated with implant dentistry. This technology has been found to be helpful in expanded areas such as presurgical planning for sinus augmentations, particulate and block bone grafting procedures. Interactive diagnostic software applications allow for enhanced manipulation of data from CT/CBCT to provide state-of-the-art diagnostic tools which create the confidence to benefit both patient and clinician in the quest for achieving predictable results.

### Take-home hints

- CBCT/CT scan technology is an extremely valuable diagnostic tool which can provide an accurate assessment of the patient’s bone and vital anatomic structures, so helping clinicians to avoid complications.
- Ideally, a scanning appliance should be fabricated in the proper plane of occlusion to be used at the time a CBCT or CT scan is taken.
- CBCT and CT can also aid in the diagnosis and treatment planning of simple to complex bone grafting, and sinus augmentation procedures.
- Three-dimensional imaging can aid clinicians in understanding the zone of the “triangle of bone” to determine viable implant receptor sites, ensure implant placement within the most volume of bone, and prevent malpositioned implants or perforations of the facial or lingual cortical plates of bone.

### Powerful interactive software applications allow further refinement of the CBCT/CT image data, allow for accurate assessment of patient anatomy, provide masking and “selective transparency” to increase visual separation of various structures, and accurate tracings of the path of the inferior alveolar nerve.

### References

Dental implant complications


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Implant complications associated with two- and three-dimensional diagnostic imaging technologies