Essential guidelines for using cone beam computed tomography (CBCT) in implant dentistry. Part 2: Clinical considerations

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Summary

The purpose of Part 2 of this series is to provide dentists with clinical guidelines and recommendations pertaining to: (i) radiographic selection criteria; (ii) indications for CBCT; (iii) how to read a data volume; (iv) application and use; and (v) the advantages and limitations of CBCT in implant dentistry. The knowledge gained and guidelines provided will enhance dentists understanding on when to use a CBCT, how to systematically analyse and read the data volume in order to maximize diagnostic and treatment planning benefits of this technology, whilst optimizing patient safety and minimizing radiation-related patient risk. The potential benefits for accurate assessment, diagnosis of pathologies, identification of anatomical landmarks and neurovascular structures, as well as topographical and morphological deviations in alveolar bone, in pre-surgical treatment planning are undisputed and has resulted in CBCT becoming the new professional standard of care as imaging modality for diagnosis and pre-surgical treatment planning in implant dentistry. A protocol is proposed on how to do a structured review and read a CBCT data volume to ensure that pathosis or critical anatomical structures are not missed that may impact on, and to enhance diagnosis, treatment planning and treatment outcomes. Additionally, CBCT imaging and 3D computer software has significantly increased the accuracy and efficiency of diagnostic and treatment capabilities, thereby contributing towards more predictable treatment outcomes and improved patient care in implant dentistry. With this technology, adequately trained dentists can enhance their practice and best serve the interests of their patients.

Introduction

The role of 3D CBCT imaging as a new diagnostic tool in modern day dentistry cannot be overemphasized and has increasingly been referred to as the 'standard of care' for diagnostic maxillofacial imaging.[1,2,3] It serves as an essential diagnostic tool for clinical assessment and treatment planning and has revolutionized every aspect of how dental implant practices are performed.[4,5,6]

Traditionally pre-operative information for dental implant diagnostics and treatment planning have been obtained from clinical examination, dental study model analysis, and two-dimensional (2D) imaging such as intra-oral peri-apical, lateral cephalometric, and panoramic radiography. These radiographic procedures, used individually or in combination, suffer from the same inherent limitations common to all planar two-dimensional (2D) projections namely, magnification, distortion and angulation discrepancies, superimposition, and misrepresentation of structures.[7] When an implant is to be placed in proximity to a vital structure, such as a nerve, artery, or sinus cavity; or where there are bone morphology discrepancies; radiographic information from traditional 2D radiographic imaging is limited due to its inadequacy to properly assess the distance in proximity to vital neuro-vascular or anatomical structures, or when implant placement is potentially violating critical cortical bone margins. The resulting errors from

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the reliance on the traditional imaging leads to potential complications, soft-tissue insufficiency, implant failure, and paresthesia.[8,9] Complications may lead to an unsatisfactory patient outcome, referral to other specialists, and subsequent medico-legal claims.[2,10]

The introduction and widespread use of CBCT imaging over the last decade has enabled clinicians to diagnose and evaluate the jaws in three dimensions, thus replacing computed tomography (CT) as the standard of care in implant dentistry.[11] Furthermore, CBCT imaging has revolutionized dento-maxillofacial radiology by overcoming the major limitations of conventional 2-D intraoral, cephalometric and panoramic radiograph[12], thereby facilitating accurate pre-surgical treatment planning that is key to successful dental implant rehabilitation. Published studies have reported improved clinical efficacy and diagnostic accuracy of CBCT[13,14], compared with standard radiographic techniques for the evaluation of implant sites with challenging unknown anatomical boundaries and/or pathological entities, and for ideal positioning of dental implants.[15,16]

The value of CBCT imaging as a diagnostic tool has also been reported for various other fields of dentistry such as oral-maxillofacial surgery, dental traumatology, endodontics, temporo-mandibular joint, periodontology, orthodontics, airway analysis and fabrication of implant surgical guides.[7,17]

As in any new technology introduced to a profession, the education lags far behind the technological advance. This is especially true of cone beam imaging. Dentists are quick to grasp the advantages and applications of using cone beam technology but, once adopted, often make the following statements: "These images are great, but what am I looking at, and where can I get more information on interpreting the scan?"[18] An important basic requirement of using CBCT imaging as a diagnostic tool is that practitioners should have appropriate training to develop critical skills for operating CBCT equipment, managing imaging software and acquiring a high level of competence and confidence in using and interpreting CBCT images. Such training should include a thorough review of normal maxillofacial anatomy, common anatomic variants, and imaging signs of diseases and abnormalities. This is particularly important for CT and CBCT imaging because of the complexity of structures within the expanded FOVs.[19]

Purpose

The purpose of Part 2 of this series is to provide an overview of the scientific literature and provide clinical guidelines pertaining to: (i) selecting the appropriate radiographic imaging modality; (ii) indications for using CBCT; (iii) how to read and analyze a CBCT data volume; (iv) clinical application and use; and (v) the advantages and limitations of CBCT in implant dentistry. The knowledge gained and guidelines provided will enhance clinicians understanding when to use a CBCT, how to systematically analyse and read the data volume in order to maximize diagnostic and treatment planning benefits of this technology whilst optimizing patient safety and minimizing radiation-related patient risk. Radiographic images used were obtained from a Kodak Carestream CS9300 CBCT unit.

Guidelines for selecting appropriate radiographic imaging modalities and indications for using CBCT

The goal of radiographic selection criteria is to identify appropriate imaging modalities that complement diagnostic and treatment goals prior to and at each stage of dental implant therapy. The following consensus-derived clinical guidelines and recommendations allow practitioners to select the appropriate imaging modality (with particular relevance to CBCT) at each phase of dental-implant therapy.[20] The American Association of Endodontists (AEE) and the American Association of Oral and Maxillofacial Radiology (AAOMR) have also jointly developed a position statement to guide clinicians on the use of CBCT in endodontics and to support decision-making when to treat or to extract.[21] Additional guidelines have also been published by the European Society of Endodontology.[22]

Initial examination

The purpose of the initial radiographic examination is to assess the overall status of the remaining dentition, to identify and characterize the location and nature of the edentulous regions, and to detect regional and site-specific anatomic structures and pathologies. The initial diagnostic imaging examination is best achieved with panoramic radiography and may be supplemented with periapical radiography.[20] The use of CBCT is not recommended as an initial diagnostic imaging examination. However, CBCT may be an appropriate primary imaging modality in specific circumstances, for example when multiple treatment needs are anticipated or when jawbone or sinus pathology is suspected.[11]

Endodontic assessment decision to treat or to extract

Radiographic imaging is an indispensable component of endodontic diagnosis and treatment planning, i.e. decision to do endodontic treatment or to extract, partial extraction therapies, and consideration of dental implant therapy. The AAE and AAOMR[21] recommend that intraoral and panoramic radiography be used for the initial evaluation of the endodontic and dental implant patient. Both of these position statements emphasize that CBCT imaging should be used only when the diagnostic information is inadequate by conventional intraoral (periapical X-rays) or extraoral (panoramic) radiography, and when the additional information from CBCT is likely to aid diagnosis and decision making for endodontic treatment or extractions, and planning for immediate or future dental implants therapy. A CBCT with limited FOV is the preferred imaging protocol for most endodontic applications.[23]

Thus, CBCT imaging should be prescribed for patients who present with nonspecific or poorly localized clinical signs and symptoms of periapical pathology, but in whom conventional radiography fails to identify such pathology. CBCT is particularly useful in investigating the potential cause for endodontic treatment failures. However, the clinician must recognize that the diagnostic accuracy is influenced by the presence of beam hardening artifacts from metal posts or gutta percha.

Pre-surgical site-specific imaging

Pre-surgical site-specific imaging must provide information supportive of dental implant diagnostics and treatment planning goals. Such information includes: (i) quantitative bone volume availability (height and width); (ii) edentulous saddle length; (iii) orientation of the residual alveolar ridge; (iv) anatomical and pathological conditions that can restrict implant placement; and (v) to facilitate prosthetic treatment planning. CBCT is recommended as the imaging modality of choice for pre-surgical diagnostics and treatment planning of potential dental implant sites.[20] CBCT imaging is also indicated if bone reconstruction and augmentation procedures (e.g., ridge preservation or bone grafting) are required to treat bone volume deficiencies before or with implant placement. The use of CBCT before bone grafting helps define both the donor and recipient sites, allows for improved planning for surgical procedures, and reduces patient morbidities.

Panoramic views of the posterior maxilla will underestimate the amount of bone available for implant placement and, if relied on, will therefore overestimate the number of clinical situations requiring a sinus augmentation. CBCT can overcome this problem as it provides more accurate measurements of the available bone volume and, in a proportion of borderline cases, will show that implants can be placed without recourse to sinus surgery.[24, 25] Because cross-sectional imaging offers improved diagnostic efficacy, it is the preferred method for preoperative assessment for sinus augmentation surgery.

Postoperative imaging

The purpose of postoperative imaging after dental implant placement is to confirm the location of the fixture and crestal bone levels at implant insertion.

Intraoral periapical radiography is recommended for this purpose and is commonly referred to as the baseline image. Intraoral periapical radiography is also recommended for periodic postoperative assessment of the bone-implant interface and marginal peri-implant bone height implants.[20]

Panoramic radiographs may be indicated for screening of more extensive implant therapy cases. Titanium implant fixtures inherently produce artifacts such as beam-hardening and streak artifacts with CBCT, obscuring subtle changes in marginal and peri-implant bone. In addition, the resolution of CBCT images for the detection of these findings is inferior to intraoral radiography.

CBCT imaging however, is indicated if the patient presents with implant mobility or altered sensation, especially if the fixture is in the posterior mandible.[20,23] to facilitate assessment, characterizing the existing defect, and planning for surgical removal and corrective procedures.

Indications for CBCT in implant dentistry

Harris and co-workers[26] provide the following guidelines for clinical situations where patients might potentially benefit from CBCT imaging for diagnosis and treatment planning.

(i) When the clinical examination and conventional radiography have failed to adequately demonstrate relevant anatomical boundaries and the absence of pathology.

(ii) When reference to such images can provide additional information that can help to minimize the risk of damage to important anatomical structures and which is not obtainable when using conventional radiographic techniques.

(iii) In clinical borderline situations where there appears to be limited bone height and/or bone width available for successful implant treatment.

(iv) Where implant positioning can be improved so that biomechanical, functional, and esthetic treatment results are optimized.

The diagnostic information can be enhanced by use of radiographic templates, computer-assisted planning, and surgical guides.[26]

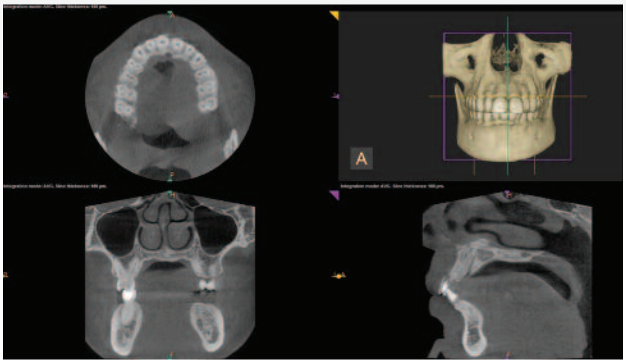


Figure 1: Orthogonal planes (10 x 10 FOV): Axial or horizontal plane (top to bottom cross sections)(upper left), 3D Rendering (upper right), Coronal or frontal plane (front to back cross sections) (lower left), and Saggital plane (right to left or buccal to lingual cross sections) (lower right)

How to do a structured review of a CBCT data volume

All CBCT volumes, regardless of clinical application, should be evaluated in a structured fashion for signs of abnormalities and to ensure that no available diagnostic and treatment planning information is missed. Dental practitioners must not be caught in the trap of only looking at the data they are interested in, such as an impacted tooth or implant site evaluation, or characterization of some pathologic entity that they found in another radiograph. They must examine all the data in the scan and must do so in a systematic and somewhat structured fashion.[18]

Reviewing CBCT scans can be performed by an adequately trained dentist or specialist treating the patient, or alternatively, a specialist maxillofacial radiologist.[20] Critical skills that dentists need for reviewing CBCT scans are: (i) know what they are looking at; (ii) mastering the CBCT imaging software and speaking the CBCT language; (iii) how to manipulate and work through the data volume; (iv) reading the CBCT; (v) analyzing and interpreting the data; (vi) understanding the different anatomical structures that can cause problems in implant placement surgery; and (vii) applying the imaging software to do virtual implant treatment planning. A wide range of video tutorials are available on You Tube and the Internet on how to use CBCT 3D Imaging Software.

To meet these CBCT reviewing objectives, clinicians need to acquire the necessary skills and images should have appropriate diagnostic quality and not contain artifacts that could compromise anatomic-structure assessments. Images should also extend beyond the immediate area of interest to include areas that could be affected by implant placement or vice versa.

The CBCT scan (data volume) provides cross sections through various planes allowing 3-dimensional evaluation of hard and soft tissues. There are three orthogonal planes (Fig.1): (i) axial or horizontal plane that provides cross sections of the data volume from top to bottom of the FOV; (ii) coronal or frontal or side view, that provides cross sectional views from front to back of the FOV; (iii) sagittal view provides cross sections from buccal to lingual, or left to right of the FOV. Besides the three planes there is also a 3-D rendering (Fig.1 – Upper right)

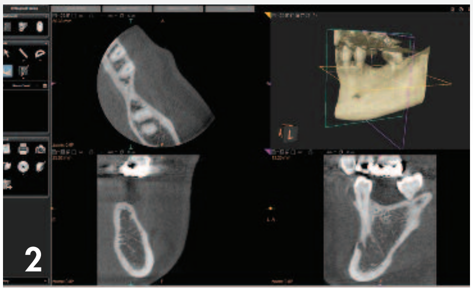
A structured or systematic approach for reading a CBCT scan is recommended because there is a huge amount of anatomy contained within the scanned volume and unless a structured approach is used, it is likely that you will miss some information that could impact on your diagnosis and treatment planning.

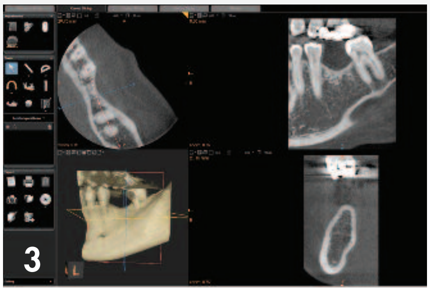
Protocol for structured reviewing of a CBCT data volume

Each section of the data volume (FOV) must be reviewed and analyzed for possible clinically significant findings. This requires discipline, and it may take some time and practice to establish a pattern so as to make it almost "second nature" to follow this process. In reviewing each of the anatomical structures in the FOV, special attention is paid to the "main complaint" or the reason for the scan acquisition. The purpose of a structured reviewing process is to prevent overlooking significant diagnostic findings that may have an impact on the success or predictability of outcome of implant treatment and any other abnormalities that may lead to medico-legal actions. The following reviewing protocol is based on the Kodak Carestream CS9300-3D unit.

(i) Clinical history: Start by reviewing the clinical history, what is the purpose of the data acquisition, which teeth have been removed when, to explain areas of bone loss with healing and/or residual alveolar bone defects. Know if previous bone grafts or socket augmentations were done previously.

(ii) Orientation: Open the patient's data volume. The default scan is usually on 'Orthogonal Slicing" (Fig.2). Select 'Curved Slicing' on the upper menu bar (Fig.3). Identify the three cross-sectional planes: axial is upper left, sagittal is upper right, 3D rendering is lower left, and coronal is lower right (Fig.3). Identify where is left and right and buccal a lingual, and the horizontal (yellow) and vertical (blue and red) lines and cursor buttons used for scouting and orientation vertically and horizontally along the planes.





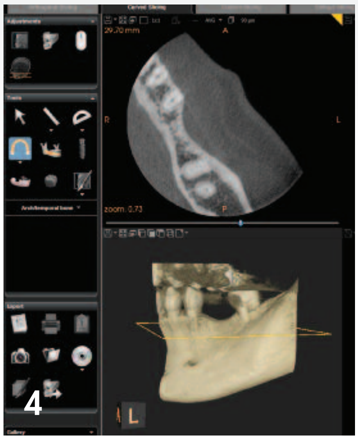


Figure 2: Opening the patients data volume defaults on orthogonal slicing. (5x5 FOV)
Figure 3: Orientation of patient's data volume on 'Curved Slicing' (5 x 5 FOV) - axial plane (upper left), sagittal plane (upper right), 3D rendering (lower left) and coronal plane (lower right)
Figure 4: Activate "Manually Create Arch" on the tools (5 x 5 FOV)

Scout the axial (Top to bottom) (yellow cursor line), coronal (front to back) (red cursor line) and sagittal (right to left) (blue cursor line) planes by moving the horizontal and vertical lines to orient yourself where you are and what you are looking at.

(iii) Set arch on the axial plane: Select the 'Manually Create Arch' icon on the tool menu on the left side of the image. (Fig.4) A text box will pop up with prompt: 'Delete Previous Arch' Select OK. Move the blue cursor button on the horizontal bar below the axial cross section to get a good cross sectional view of the roots on the arch (Fig.4). Click and draw an arch through the center of the root from left to right side (Fig.5).

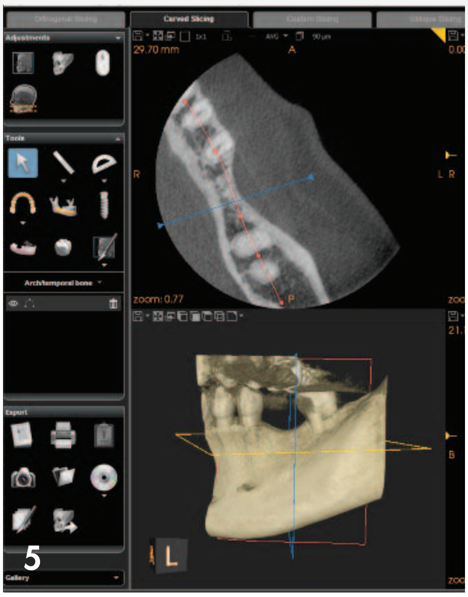
(iv) Scouting the coronal cross section: Go to the sagittal plane (upper right cross section) (Fig.6). Move the vertical cursor (Blue) from left to right on the FOV to review the coronal cross section (lower right) to identify clinically significant pathosis and neurovascular structures (Fig.6). Return again to the center of the area of interest with the vertical line in the sagittal cross sectional plane.

(v) Scouting the sagittal cross section: Go to the coronal cross section (lower light) (Fig.6). Move the red cursor of the vertical line from buccal to lingual (left to right) to review the upper sagittal cross section to identify any clinically significant pathosis and neurovascular structures. Return again to the center of the area of interest with the red vertical line in the coronal cross sectional plane. (Fig.6) At this stage the 'Nerve Canal Tool' icon can be activated to plot the inferior alveolar nerve. (Fig.7)

(vi) Review area of interest (Implant site): Lastly scout and assess the region of interest (implant site) and adjacent teeth. Note any morphological abnormalities, neurovascular structures, anatomical structures (sinus, nasal), and residual alveolar ridge morphology or other clinically significant findings that may have an impact on implant treatment planning. Move the horizontal line of the sagittal cross section (upper right) to 1mm below the crestal level. (Fig.6)

(vii) Implant treatment planning: Software tools can now be applied to facilitate implant treatment planning. Activate the 'Measurement Mode' icon in the 'Tools Menu' (Fig.7). Go to the axial cross section (upper left) and click buccal and then palatal to measure the bucco-palatal width. Go to sagittal cross section (upper right) and click mesial to distal of the implant site to measure the saddle length of the residual alveolar ridge (Fig.7). Go to the coronal cross section (lower right) and measure the width and length of the residual alveolar bone (Fig.7). If the implant site is in the lower posterior mandible then measure from the crestal level to 2 mm above the inferior alveolar nerve. The correct implant diameter and length can now be selected for this implant site.

(viii) Virtual implant selection and placement: Position the vertical line in the correct position of the osteotomy site in the coronal cross section (Lower right). Activate the 'Implant Placement Tool' icon in the 'Tool Menu' (Fig.8). Select the desired implant type, diameter and length according to the abovementioned measurements. Adjust fine tuning of the implant in its correct three dimensional position by checking all three planes (axial, sagittal and coronal (Fig.9). A stent can also be used to position the vertical line in the correct position where the implant must be placed. (Figure 10)
Check placement of the implant in all three planes to assess whether the cortical plate, anatomical structures such as the sinus and nasal cavity, neurovascular structures and neighboring teeth are not violated and that the implant is



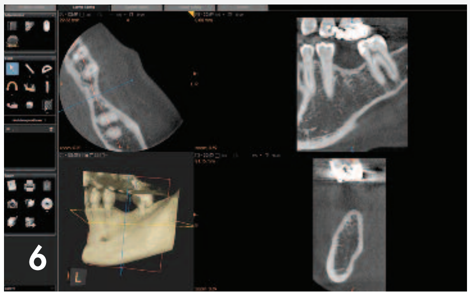


Figure 5: Setting the arch on the axial plane by clicking on centre of the roots to draw an arch (red dots and line).
Figure 6: Scouting the data volume & reviewing the area of interest.
Figure 7: Activating 'Nerve Canal Tool' icon to plot the inferior alveolar nerve and 'Measurement mode' icon for measuring the implant osteotomy site. Typical implant treatment planning measurements –are saddle length (mesio-distal) (upper right), residual alveolar bone width (bucco-lingual) and vertical length (occlusal-apical) (lower right).

placed in the correct 3D position in the residual alveolar bone for optimal implant stability and a successful prosthetic restoration. Go to the menu bar above the sagittal cross section (upper right) and select 'Set Integration' and select 15mm on the scroll down menu to activate ray sum for the sagittal cross section to simulate a typical panoramic X-ray. The magnification tool can be used to better assess the area of interest (Fig.11) The virtual implant planning and placement can now be communicated visually and discussed with the patient.

Application of CBCT imaging in implant dentistry

Successful and predictable implant dentistry requires accurate pre-surgical diagnostics and treatment planning information of the amount of bone available, bone density and the proximity to anatomical structures. Health care providers are also obligated to acquire adequate information from patients to provide a basis for informed patient consent.[18] Clinical complexity, regional anatomic considerations, potential risk of complications and aesthetic considerations in the location of implants are factors that determine the individual clinicians needs for information supplemental to that already obtained from the clinical and radiographic examinations (peri-apical and panoramic) to formulate a diagnosis and to assist in implant therapy treatment planning.[27]

The introduction and widespread use of cone beam computed tomography (CBCT) over the last decade has enabled clinicians to diagnose and evaluate the jaws in three dimensions, thus replacing computed tomography (CT) as the standard of care for implant dentistry.[11] Additionally, multiplanar imaging-reformatting (MPR) of CBCT has significantly increased diagnostic accuracy and efficiency[13,14] and offers an unparalleled diagnostic approach when dealing with previously challenging unknown anatomical boundaries and/or pathological entities.[15] This has prompted several different organizations to develop clinical guidelines and recommendations for the appropriate use of CBCT for assessing potential dental implant sites. These include the American Academy of Oral and Maxillo-Facial Radiology (AAOMR),[20] European Academy of Osseointegration (EAO),[26] International Congress of Oral Implantologists (ICOI),[28] the Academy for Osseointegration (AO)[29] and the International Team for Implantology."(ITI).[11]

Cone beam computed tomography (CBCT) has applications in several aspects of dentistry. To appropriately use this technology, clinicians should be able to identify those

Figure 8: Activate the 'implant placement tool' icon to select the type of implant, implant diameter and length.

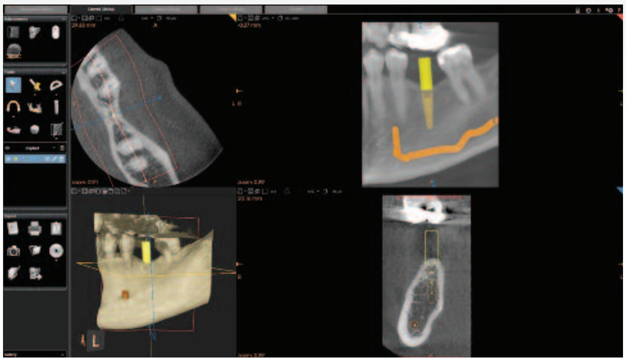


Figure 9: Virtual implant placement in the correct 3D position.

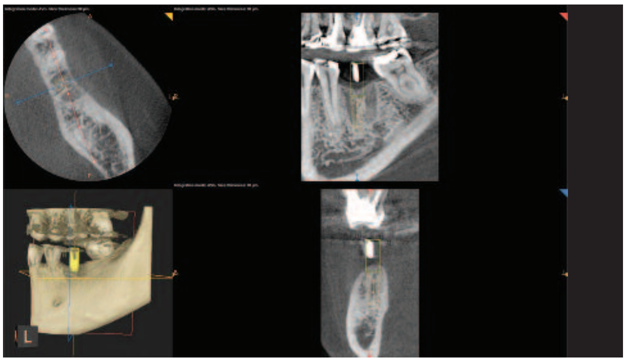


Figure 10: Using a radiographic stent for virtual implant placement.

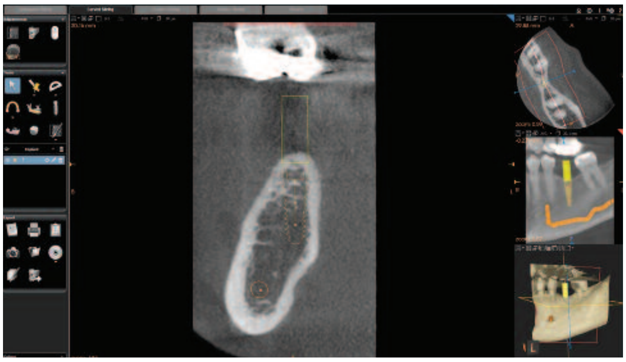


Figure 11: Using the magnification tool to assess views in close-up to check that the implant is placed in the correct 3D position.

situations where the information from CBCT is likely to provide useful information, and where this additional information translates into enhanced diagnoses, treatment plans and treatment outcomes.[23] The application or use of CBCT in implant dentistry includes: (i) pre-surgical diagnostics and treatment planning; (ii) computer-assisted treatment planning; and (iii) postoperative evaluation focusing on implant failures and complications due to damage of neurovascular structures.[13,16]

Pre-surgical diagnostics and treatment planning

Radiographic assessment of the 3D implant position, angulation, and restorative space is essential during pre-surgical diagnostics and treatment planning of implant sites within the residual alveolar bone. Positioning of single implants within the dental arch can be challenging considering the proximity to adjacent tooth roots, vital structures, occlusal plane, and relative position within the arch.[30] CBCT imaging therefore must provide information supportive of the following goals, namely (i) to establish the quantitative bone availability (morphologic characteristics) of the residual alveolar ridge; (ii) to determine the orientation of the residual alveolar ridge; and to (iii) identify local anatomic or pathologic boundaries within the residual alveolar ridge limiting implant placement.[16]

Quantitative bone availability of the residual alveolar ridge (amount of bone available at the implant site

Effective pre-surgical assessment requires that clinicians interpret implant sites for many factors related to predictable and successful implant restorations, including adequate bone volumes, distance away from teeth/implants, sufficient prosthetic space for restoration, and precise implant placement. Essential pre-surgical assessment should include an evaluation of the saddle length (mesio-distal), vertical bone height (occlusal-apical), and horizontal width (bucco-lingual) bone availability of the proposed implant recipient site (Fig.7) to facilitate proper planning, correct implant selection, 3D placement of the dental implant (Fig.9) and the necessity for implant site development.[20,30]

Most CBCT viewing and analyses software packages feature measurement tools that can be used to easily determine the height and width of bone and the proximity of the proposed implant placement site to adjacent vital structures. With this software the clinician can accurately visualize the 3D alveolar ridge bone contour of a patient and make determinations about surgical entry, implant diameter and length, and prosthetic requirements before the surgical procedure.[30]

CBCT also provides a qualitative assessment of the type of bone (bone quality) and local trabecular architecture (Fig.12a-12c and 13a-13d) to assist in selecting the correct implant type to optimize implant stability. The standard practice is to visually analyze trabecular density and sparseness at the edentulous site. Some studies have explored the feasibility of measuring CBCT gray values at the edentulous area to infer bone quality.[31,32] However, there is strong evidence that the relationship between gray value and object density is markedly influenced by several factors, including exposure parameters, FOV and anatomic location.[33,34,35,36] Thus, current gray value approaches to quantitatively assess bone quality are unreliable.

CBCT is an essential tool to identify the extent and size of bone defects at potential implant sites that may require augmentation or site development to prepare it for simultaneous or later implant placement.[26]

Examples where augmentation or site development procedures are required are horizontal bone volume deficiencies (Fig.14), fenestration defects (marginal bone intact) (Fig.15), dehiscence bone defects (denuded areas extend through the marginal bone (Fig. 16a & 16b), post extraction site ((fig.17), vertical bone deficiency (Fig.18), and combined horizontal and vertical bone deficiencies of the alveolar ridge (Fig.19), and sinus floor elevations (Fig.20).

The use of CBCT before bone block grafting helps define both the donor and recipient sites, allows for improved planning for surgical procedures, and reduces patient morbidities.

Ridge morphology (Bone shape and quality) Shape and quality of the bone available

The bucco-lingual ridge pattern cannot be viewed on 2D radiographs, but CBCT provides the advantage of showing the type of alveolar ridge pattern present. Cross-sectional images (coronal view) provide the implantologist with the appearance of ridge patterns, such as irregular ridge (Fig.21a, 21b), narrow crestal ridge (Fig. 21c, 21d)), and knife shape ridge (Fig.21e and Fig.22). Also, the loss of cortical plates and undulating concavities (Fig.23) can also be appreciated on cross-sectional images, and they cannot be seen on panoramic images. In the case of a compromised jaw bone (in terms of quality and/or quantity of bone), the panoramic technique is an inefficient imaging tool. In case of potential risks in treatment plan 3D imaging may prove indispensable.

Bone quality is not only a matter of mineral content, but also of structure. It has been shown that the quality and quantity of bone available at the implant site are very important local patient factors in determining potential implant stability and the success of dental implants. Bone quality is categorized into four groups: groups 1–4 or types 1–4 (Bone Quality Index):[37]

Type 1: homogeneous cortical bone; (Fig.13a)
Type 2: thick cortical bone with marrow cavity; (Fig.13b)
Type 3: thin cortical bone with dense trabecular bone of good strength (Fig.12a, 13c); and
Type 4: very thin cortical bone with low-density trabecular bone of poor strength. (Fig.12c)

In the jaws, an implant placed in poor-quality bone with thin cortex and low-density trabeculae (Type 4 bone) has a higher chance of failure compared with the other types of bones. This low-density bone is often found in the posterior maxilla, and several studies report higher implant failure rates in this region.[37]

Topography and orientation of the residual alveolar bone

The orientation and residual topography of the alveolar-basal bone complex must be assessed to determine whether or not

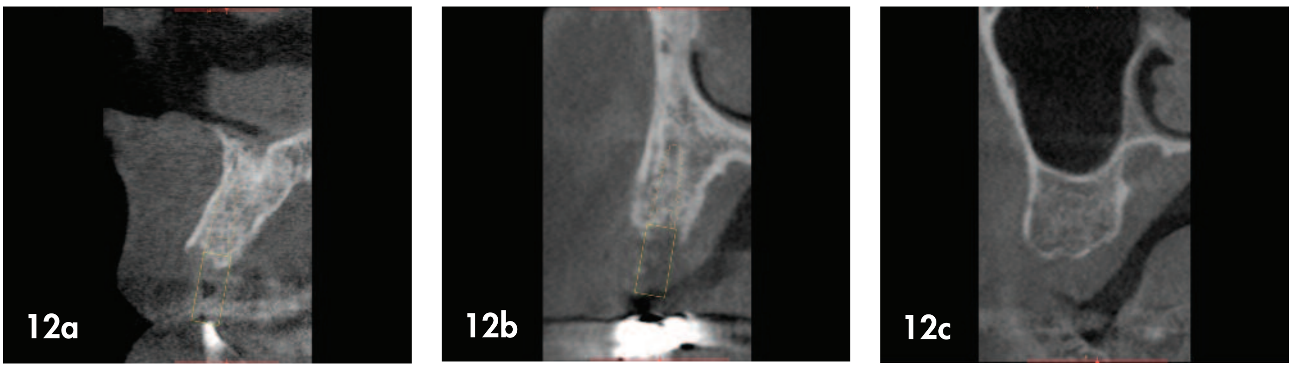


Figure 12: Qualitative pre-surgical assessment of alveolar bone and trabecular architecture in the maxilla Figure 12a: (Type 2 bone). Figure 12b: (Type 3 bone). Figure 12c: (Type 4 bone).

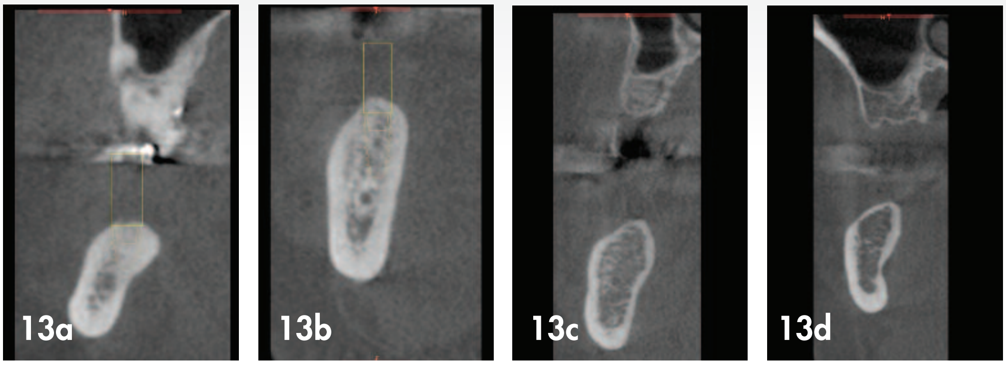


Figure 13: Qualitative pre-surgical assessment of alveolar bone density and trabecular architecture in the mandible. Figure 13a: (Type 1 bone). Figure 13b: (Type 2 bone). Figure 13c: (Type 3 bone). Figure 13d: (Type 4 bone).

there are variations that could compromise the alignment of the implant fixture with the planned prosthetic restoration. This is particularly important in the mandible (e.g., submandibular gland fossa) (Fig.24) and anterior maxilla (e.g., labial cortical bone concavity).[20] (Fig.25) Information on the topography and orientation of the residual alveolar bone is important to optimize implant selection and placement.

Anatomical considerations, boundaries and limitations (important anatomic landmarks

Each location in the dental alveolus has unique morphologic and topographical characteristics owing to edentulousness and specific regional anatomic features that need to be identified and assessed in the diagnostic and treatment planning phase of dental-implant therapy.[20] The clinician must have full knowledge of oral-bone anatomy, boundaries and limitations so that any osseous-topography, bone-volume excesses/deficiencies can be identified, to facilitate optimal implant placement and to avoid surgical complications.[20] A comprehensive overview of the Oral and Maxillofacial anatomy is provided in the literature.[15, 37,38,39,40,41,42] For the purposes of this article only the critical anatomical elements related dental implantology is presented.

Anterior maxilla

The maxillary anterior region (commonly referred to as the esthetic zone) often presents both surgical and prosthetic implant-assessment complexities.[43,44]

Subsequent to tooth loss, decrease in the height and/or width of the alveolar process and the development of a labial concavity often necessitate bone augmentation to facilitate implant placement.[45] (Fig.25) The morphology and dimension of the nasopalatine (incisive canal) (Fig.26a-26d)[46,47,48,49] and the location of the floor of the nasal fossae may also compromise bone availability for implant placement.

Posterior maxilla

Atrophy of the edentulous posterior alveolar ridge and pneumatization of the maxillary sinus are the most common causes of lack of bone availability for implant placement in the

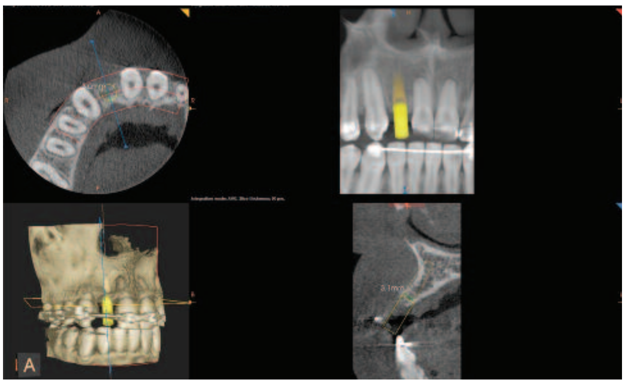


Figure 14: Horizontal bone volume deficiency requiring augmentation.

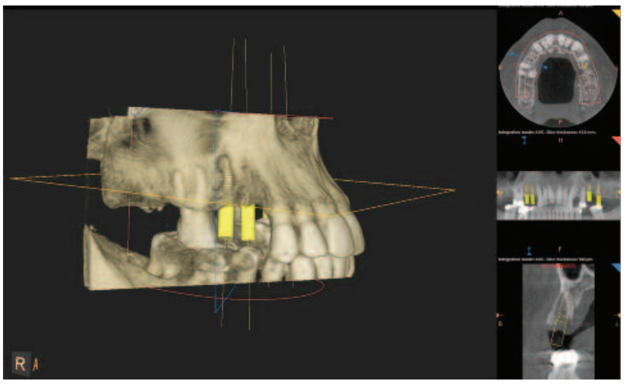


Figure 15: Fenestration defect (marginal bone intact) requiring buccal bone augmentation.

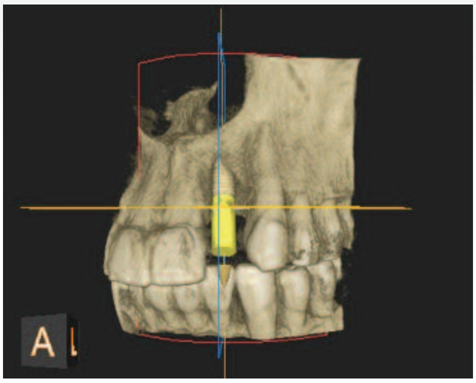


Figure 16a: 3D rendering of a dehiscence defect (denuded areas extend through marginal bone) requiring horizontal buccal bone augmentation.

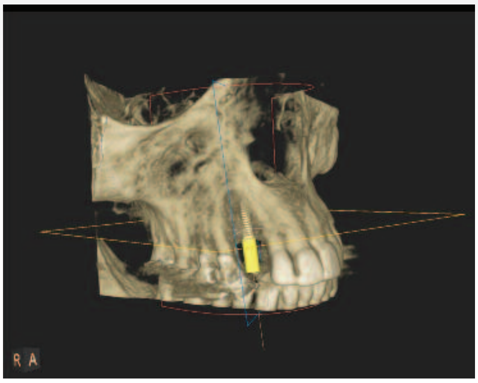


Figure 16b: 3D rendering of a dehiscence defect (denuded areas extend through marginal bone) requiring horizontal buccal bone augmentation.

posterior maxilla. Additionally, the maxillary posterior region has the lowest bone density (Fig. 12c) and the highest implant failure rate.[50] Sinus floor elevation surgery along with bone grafting is a well-accepted technique before, or simultaneously with implant placement to increase support in an atrophic maxilla.

Knowledge about the sinus anatomy and residual alveolar ridge is critical before the conduction of surgical procedures. CBCT images provide an accurate 3-dimensional (3D) representation of the anatomy and are suitable for the detection of morphologic variations in the maxillary sinus to assist with presurgical assessment for sinus augmentation surgery, implant planning and placement.[40,42]

The available residual alveolar ridge in the posterior maxillary premolar and molar regions are limited superiorly by the floor of the maxillary sinus. (Fig.20)

Anatomical variations of the maxillary sinuses such as the presence of septa (also known as Underwood septa), number, location and shape, particularly in the inferior sinus wall, complicate sinus floor elevation surgical procedures.[23] Sinus septa are bony projection commonly found in the inferior or lateral sinus walls separating the maxillary sinus into 2 or more compartments (Fig.27). Studies show that approximately 45 per cent of patients had at least one septum.[51] Strong sinus membrane adhesion at the location of septa, particularly of the inferior sinus wall, may cause perioperative complications, therefore the presence, extent and location of septa must be accurately detected in presurgical radiographic imaging to facilitate proper selection of the surgical technique and prevention of unwanted peri-operative complications and thus increase success rate of sinus surgeries.[41,51] Medium-sized or long septa may necessitate a modified surgical approach. Detection of septa may also influence the decision about the location of the window in the lateral window approach during sinus floor elevation surgery.

Assessment of the anterior recess of the maxillary sinus is also important if markedly angled implants are considered for implant-supported edentulous prostheses.)

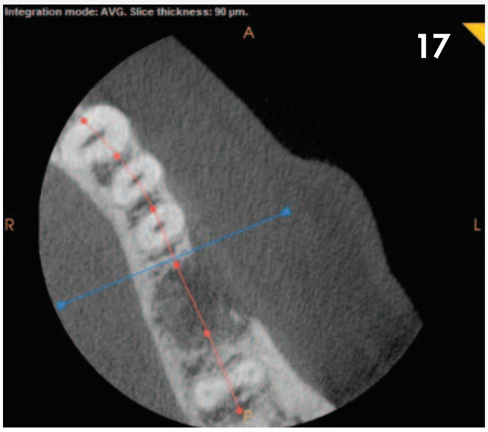
CBCT can also provide information on arterial channels in the lateral wall of the sinus, presence of apical pathosis (Fig.28) as well as on the health of the sinus such as absence of sinus membrane thickening(Fig.29). In some clinical situations, when there is evidence of sinus pathology, or it is the clinicians opinion that sinus drainage is impaired and may jeopardize the outcome of the procedure to be undertaken, there may be a justification to extend the FOV to include the whole of the sinus including the osteo-meatal complex.[52,53,54]

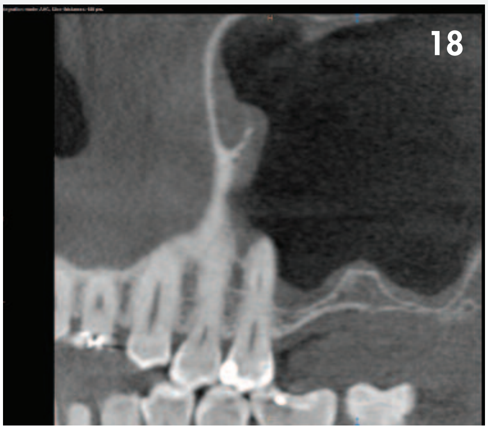
Anterior mandibula

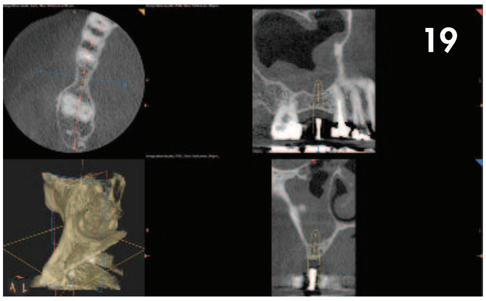
The anterior mandible is a relatively safe location for implant placement. However, proper diagnostics are essential to avoid intraoperative and postoperative hemorrhage, neurosensory loss, and risk of perforating the cortical plate. The locations of osseous structures (buccal and lingual cortical plates) (Fig.30) and neurovascular structures include the lingual foramen (Fig.30), the terminal branch of the inferior alveolar nerve at the mental foramen and the anterior loop (Fig.31, 32). The mental foramen is a strategically important landmark during osteotomy procedures in the mandible. Its location and the possibility that an anterior loop of the mental nerve may be present mesial to the mental foramen needs to be considered before implant surgery to avoid nerve injury.[55]

Posterior mandibula

In the posterior mandible, there are several anatomic







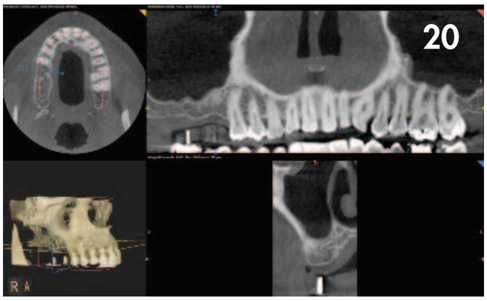


Figure 17: Axial view of a post extraction site at 8 weeks (5x5 FOV).
Figure 18: Vertical bone deficiency in the posterior maxilla.
Figure 19: Combined horizontal and vertical alveolar ridge bone discrepancy in the posterior maxilla.
Figure 20: Vertical alveolar bone deficiencies in the posterior maxilla requiring sinus floor elevation (5 x 10 FOV).

structures that can compromise prosthetically driven, dental-implant placement. The most important landmarks in the posterior mandibular are the inferior alveolar canal and the submandibular gland fossa (Fig.33, 34, 35). Both these structure can present with anatomic variations that may restrict implant placement and result in complications.

Correct identification of the inferior alveolar (mandibular) canal may assist the clinician to avoid damaging the nerve during surgery and thereby preventing the occurrence of complications such as impaired sensory function and paresthesia of the lower lip and the neighbouring soft tissues,[56] It is advisable to measure from the crest of the alveolar bone to the coronal aspect of the IAN and subtract 2 mm to provide a safety zone.

The submandibular fossa is denoted by a lingual concavity or undercut in the posterior mandible and contains the submandibular gland. (Fig.33,34,35)

Physiological, biological and pathological considerations

Other local anatomic boundaries and limitations or pathologic conditions that could potentially restrict implant placement and cause complications include: (i) inadequate distance between neighbouring teeth; (ii) angulation of roots; (iii) apical pathology on neighbouring teeth (Fig.28,36); (iv) impacted teeth (Fig. 36, 37) (iv) residual roots; and (v) presence of foreign material (Fig.38).

Computer assisted prosthetic and surgical treatment planning

Apart from the diagnostic capabilities, dental CBCT may also offer therapeutic capabilities through computer assisted surgical and prosthetic treatment planning via computer-aided design/computer-aided manufacturing solutions.[13,26]

CBCT DICOM data is merged with stereolithography (STL) files from an Intra-Oral optical scanner to produce a 3D rendering (3-D Conversion) model of the jaw for virtual planning.[30] Virtual planning software is used to construct a virtual wax-up and to place the implant fixture its correct 3D-position on the virtual 3-D model. Information to be gathered from the combination of high-quality CBCT images and STL-files should include locations of vital structures, desired implant positions and dimensions, the need for augmentation therapy,

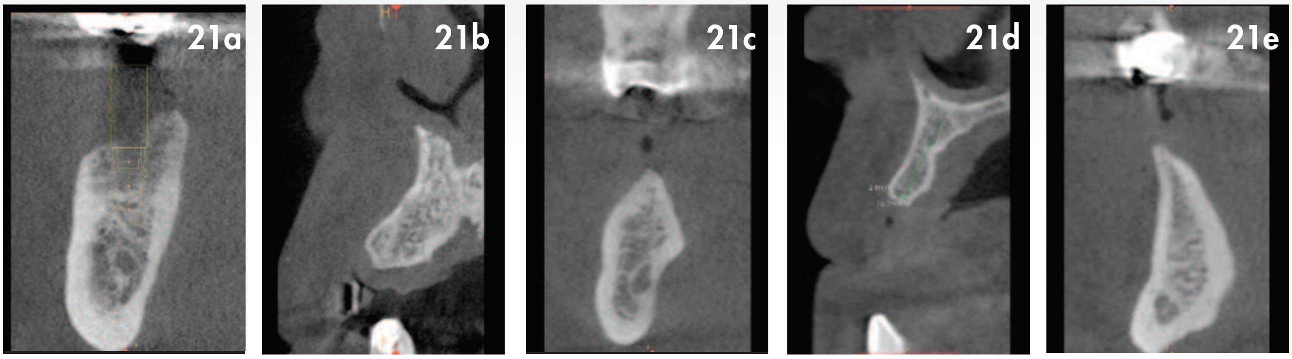


Figure 21a: Coronal view of an irregular alveolar ridge in the maxilla.
Figure 21b: Coronal view of an irregular alveolar ridge in the mandibula.
Figure 21c: Coronal view of a narrow crestal alveolar ridge in the mandibula.
Figure 21d: Coronal view of a narrow crestal alveolar ridge in the maxilla.
Figure 21e: Coronal view of a knife–shape crestal alveolar ridge in the mandibular.

and the planned prostheses.[11] Once the design is completed it is submitted to a milling machine or a digital printer for fabrication of a surgical guide. The guide can be bone, tooth or mucosal supported. The actual surgical guide is milled or printed, all with round cylinders, allowing dedicated instrumentation (drill bits) to be precisely guided, creating osteotomies and guiding the implant in its correct or ideal 3D-position during placement.[11] Implants placed utilizing computer-guided surgery with a follow-up period of at least 12 months demonstrate a mean survival rate of 97.3% (n = 1,941), which is comparable to implants placed following conventional procedures.[11]

To improve image data transfer, clinicians should request radiographic devices and third-party dental implant software applications that offer fully compliant DICOM data export.[11] It is important to realize that errors can occur when transferring information from a cross-sectional computer image to the surgical situation. The surgeon should be aware of these and be careful to allow an adequate "safety margin" in all cases.[26] The use of guided surgery for implant placement is increasing because of a number of clinical advantages, including increased practitioner confidence and reduced operating time.

Post-operative radiographic assessment of implant failures and complications

(i) Altered sensation and possible damage to neurovascular structures

CBCT may offer surgical guidance and therapeutic possibilities and cases of altered sensation and possible damage to neurovascular structures. Current evidence supports the protocol that a CBCT be used following the neurosensory assessment to pinpoint lesion location as well as confirmation of IAN injury.[57] Proper pre-surgical planning,

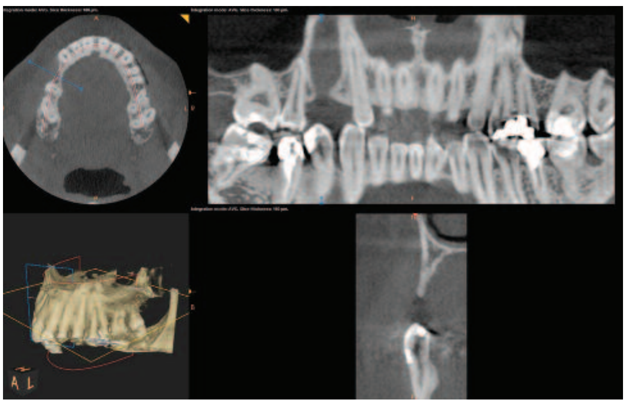


Figure 22: Knife–shape crestal alveolar ridge in the posterior maxilla.

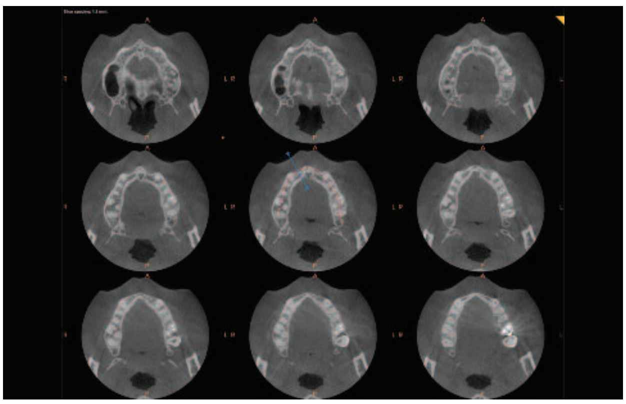


Figure 23: Serial axial images of the maxilla showing undulating buccal bone concavities due to missing anterior teeth (5 x 10 FOV).

timely diagnosis, and treatment are key factors in avoiding and managing neurovascular complications and damage after implant placement (Fig.38).[57]

(ii) Infection or post-operative integration failure

CBCT is indicated for implant failure cases, infection or post-operative integration failure, owing to either biological or mechanical causes. A CBCT can provide therapeutic assistance with characterizing the existing defect, plan for surgical removal and corrective procedures, such as ridge preservation or bone augmentation, and assess what the implications of surgical intervention is on adjacent structures. Cross-sectional imaging, optimally CBCT, should also be considered if implant retrieval is anticipated.[20]

(iii) Implant displacement

The use of CBCT scans are helpful in post-operative evaluation of implant displacement into the sinus or nasal cavity (Fig.39).[58]

(iv) Perforations

The major potential risks of encountering a lingual plate perforation (Fig.40) are massive haemorrhage of the submental and sublingual arteries (anterior mandible)[59] and airway obstruction[60] Perforation of the lingual concavity above the mylohyoid ridge might injure the lingual nerve.[61] If the extruded implant is left unattended, the infection might spread to the parapharyngeal and retropharyngeal space, leading to more severe complications, such as mediastinitis, mycotic aneurysm formation with possible subsequent rupture of the internal carotid artery, and internal jugular vein thrombosis with septic pulmonary embolism or upper airway obstruction.[62]

Advantages and limitations of CBCT in implant dentistry

There are six major benefits of cone beam CT scan (CBCT) for dental implant planning and placement:[63]

Precision placement of implants in the bone: CBCT allows the surgeon to accurately measure and localize the available bone and accurately place the implant in a correct 3D position. This is verified by virtual implant placement.

Proper orientation of the implant with its overlying restoration: A CBCT can be merged with an optical scan of the patient's teeth (digital impression) to create a complete bone, teeth, and soft tissue digital model. This will facilitate precise postioning of implants to support planned restorations. This prevents misaligned implants, which may be difficult or impossible to restore, and avoids poor aesthetics and function.

Prevention of injury to nerves: Using the CBCT, the surgeon maps out the path of the sensory nerves in the jawbone and selects the right implant length. Conventional X-rays are flat and distorted and are poor diagnostic images for predicting the position of the nerves. Nerve damage from dental implant placement results in partial or complete numbness of the lip and chin area, which can be potentially permanent. CBCT is a mandatory imaging technique to prevent this serious complication.

Prevent implant penetration into the sinus: CBCT provides an accurate picture of the maxillary sinus and its position in relation to the available bone. The surgeon can make an accurate measurement and select the right implant length to avoid puncturing the maxillary sinus. Penetration of the maxillary sinus can lead to sinusitis or other inflammatory conditions. The surgeon can also plan for necessary bone grafting if there is insufficient bone to support the implant. Conventional X-rays are highly inaccurate for these purposes and do not provide the information necessary for the safe placement of dental implants in the posterior maxilla.

Selection of the right size implant for optimal support: The longevity and success of dental implants require maximal integration and stability in the bone. CBCT allows the surgeon to measure the available bone and select the widest and longest implant appropriate for the site. This, in turn, helps to support the high bite (occlusal) forces and avoid potential failure from overload. Implant size selection should

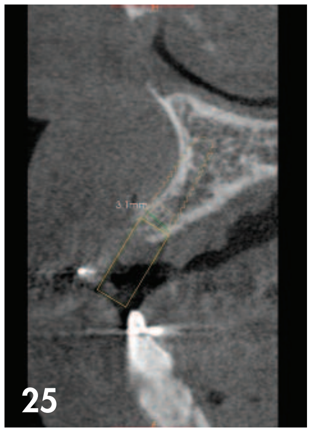


Figure 24: Coronal view of the topography and orientation of the residual alveolar bone in the submandibular gland fossa area.

Figure 26a: Axial view of morphology of the nasopalatine canal (incisive canal) in the anterior maxilla (5 x 10 FOV).

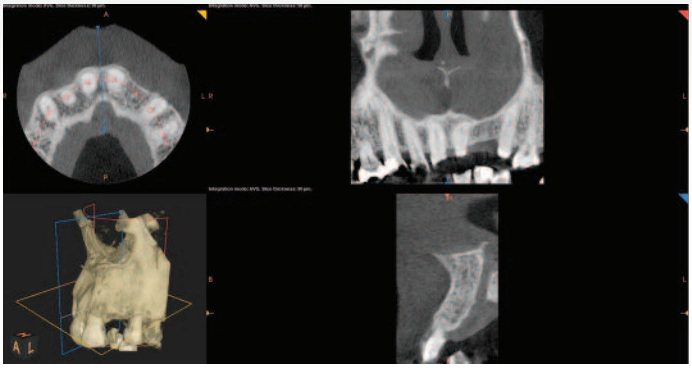


Figure 26b: Coronal view of morphology of the nasopalatine canal (incisive canal) in the anterior maxilla (5 x 10 FOV).

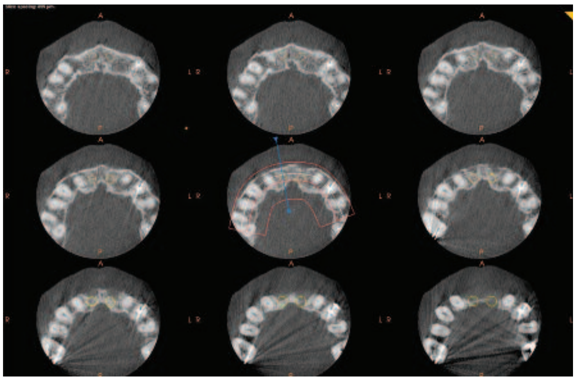


Figure 26c: Serial axial views of the nasopalatine canal.

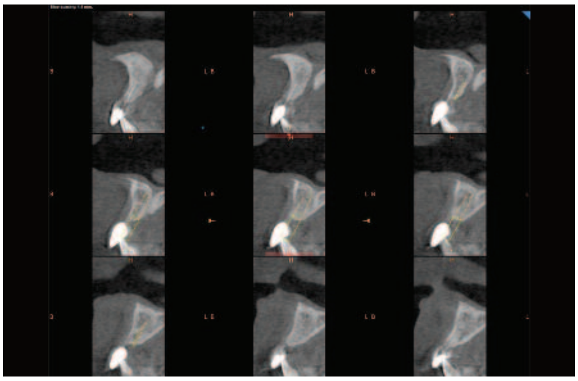


Figure 26d: Serial coronal views of implant placement planning in relation to the nasopalatine canal in the anterior maxilla.

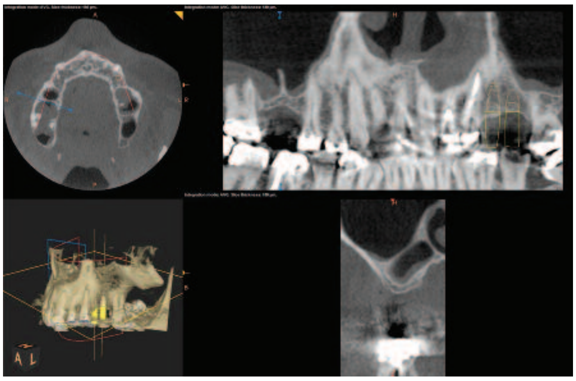


Figure 27: Sinus septa in the inferior sinus wall.

Figure 27: Apical pathosis in the posterior maxilla.

not be guesswork! Implant selection is made based on precise measurements, biological requirements, bite scheme, and individual patient needs.

Improved clinical outcomes and reduced risk of complications

CBCT offer a more accurate, predicatable outcome and safer means to dental implant placement. CBCT should be a mandatory diagnostic imaging for every implant treatment. Not using CBCT for planning is unwise for the surgeon and creates unnecessary risk for the patient and clinician.

Communitation of data volume

CBCT allows the ability to communicate DICOM data imaging information for prosthetic restorative planning, and design and manufacturing of surgical guides.

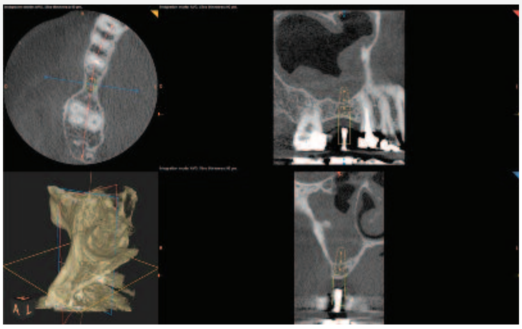


Figure 29: Implant planning in the posterior maxilla and sinus membrane thickening.

Figure 30: Buccal and lingual cortical plates in the anterior mandibula and lingual foramen.

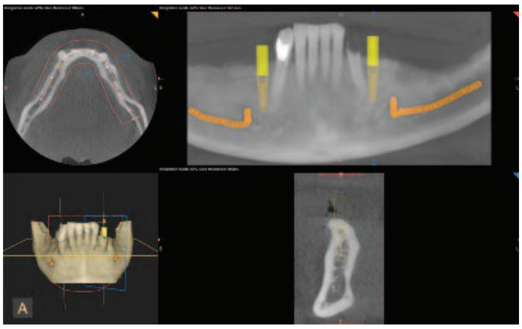


Figure 31: Mental foramen and anterior loop and terminal branch of the inferior alveolar nerve.

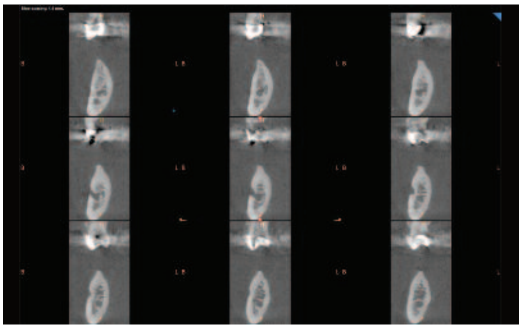


Figure 32: Serial coronal cross sections of mental foramen in the anterior mandibula.

Limitations of CBCT

Requires training and has a learning curve

It requires new competencies from the clinician and the value of information obtained is interpretation sensitive. This requires training and new knowledge from the clinician.[64]

Large FOV may requires expertise and specialized monitoring equipment

Referral to an Oral Maxillofacial Radiologist may be indicated for need of expertise and because a proper monitor, ambiente lighting, and equipment settings may be available only in a specialist radiologist environment[64], especially where larger FOV are required for advanced and full dental reconstructions.

Poor soft tissue contrast

One major disadvantage of CBCT is that it can only demonstrate limited contrast resolution. If the objective of the examination is hard tissue only, then CBCT would not be a problem. However, CBCT is not sufficient for soft tissue evaluation.[7,65] It provides limited resolution to deeper (inner) soft tissues and MRI and CT are better for soft tissue imaging.[64]

Imaging artifacts

Streaking and motion artefacts, although limited, cannot be avoided. These artifacts contribute to image quality degradation and can lead to inaccurate or false diagnosis.[64,68]

Bone density and grayscale

CBCT is commonly used for the assessment of bone quality primarily for pre-implant treatment planning. Traditionally bone quality has been based on bone density, estimated through the use of Hounsfield units derived from multidetector CT (MDCT) data sets. However, due to crucial differences between MDCT and CBCT, which complicate the use of quantitative gray scale values (GV) for assessment of bone density with CBCT.[66] Experimental and clinical research suggest that the qualitative use of GV in CBCT to assess bone density should be avoided at this stage.[66] Current scientific literature suggests a paradigm shift of bone quality assessment from a density-based analysis to structural evaluation.[66]

Radiation dose

The radiation dose from CBCT is lower than conventional

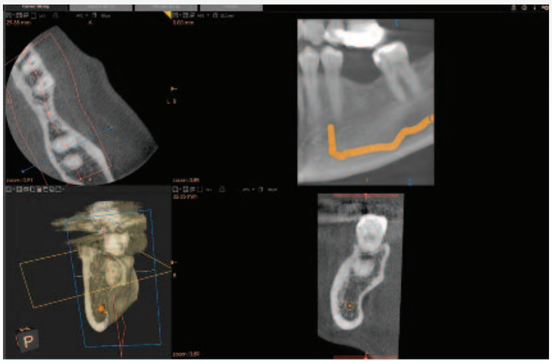


Figure 33: Inferior alveolar canal and submandibular gland fossa in the posterior mandibula.

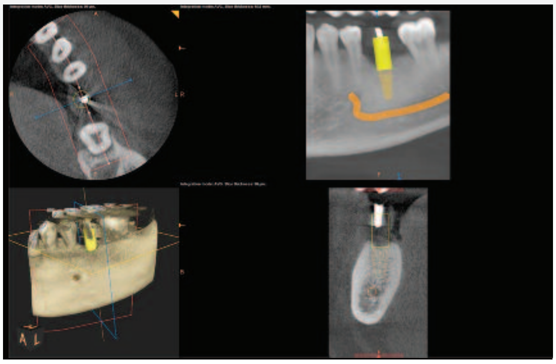


Figure 34: Inferior alveolar canal and mental foramen showing the anterior loop of the mental nerve.

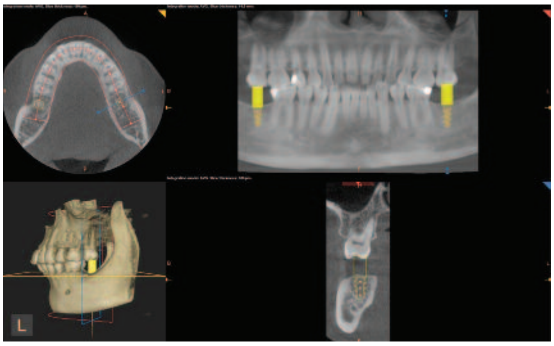


Figure 35: Implant planning in the posterior mandibular showing implants in relation to the inferior alveolar canal and the submandibular glad fossa.

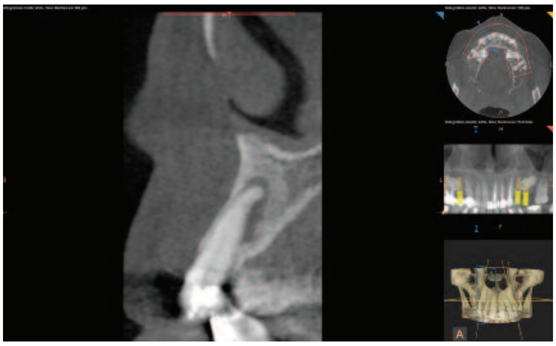


Figure 36: Apical pathosis en impacted premolars.

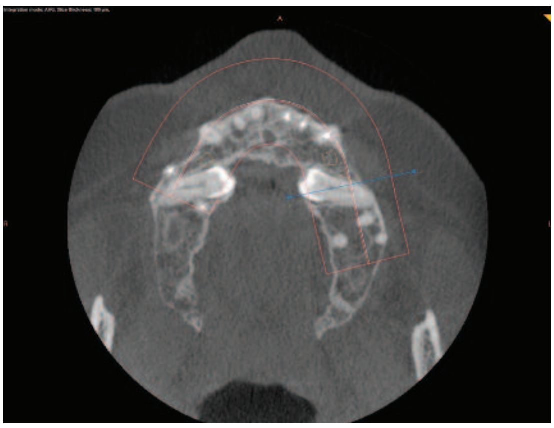


Figure 37: Axial view of impacted premolars in relation to the osteotomy sites.

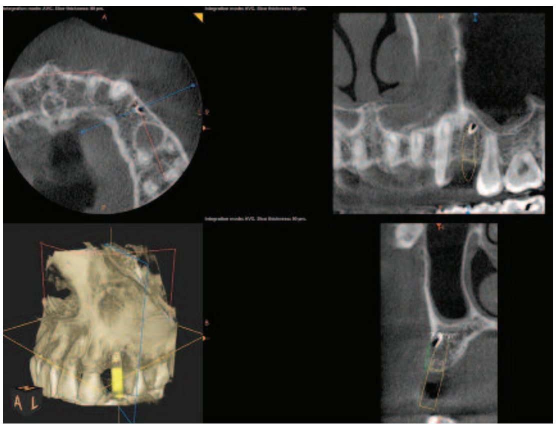


Figure 38: Foreign body located in the osteotomy site.

CT, but is significantly higher than traditional radiographic modalities (peri-apical, Panoramic).[64]

Conclusions

CBCT imaging technology computer software has significantly increased the accuracy and efficiency of diagnostic and treatment capabilities, thereby offering an unparalleled diagnostic approach when dealing with previously challenging unknown anatomical and/or pathological entities in implant dentistry. The potential

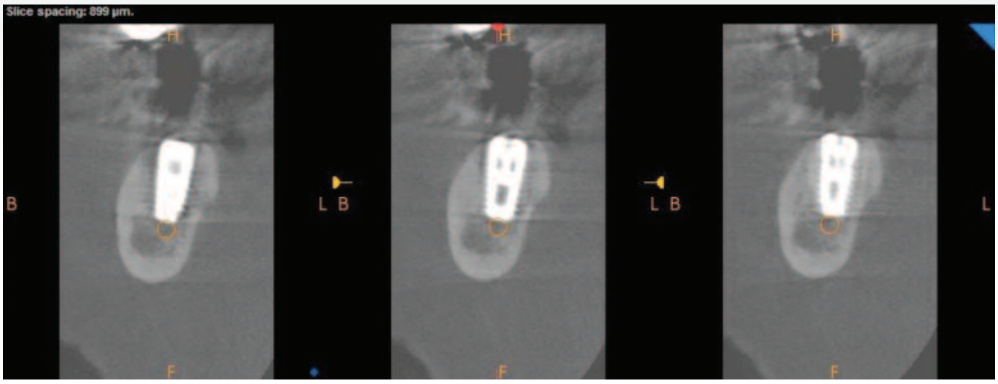


Figure 38: Using CBCT for neurosensory assessment and confirmation of inferior alveolar nerve injury. (With permission from Dr Howard Gluckman).

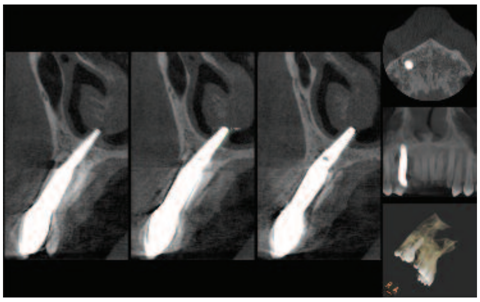


Figure 39: Using CBCT for post-operative assessment of complications such as implant placement into the nasal cavity (With permission from Dr Howard Gluckman).

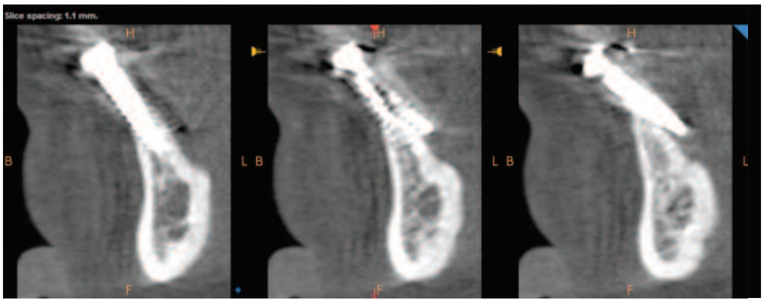


Figure 40: Implant perforating the lingual cortical plate (With permission from Dr Howard Gluckman).

benefits for accurate assessment, diagnosis of pathologies, identification of anatomical landmarks and neurovascular structures, as well as topographical and morphological deviations in alveolar bone, in pre-surgical treatment planning are undisputed. CBCT has thus become the new professional standard of care as imaging modality for diagnosis and pre-surgical treatment planning in implant dentistry.

The decision to prescribe a CBCT scan must be based on the patient's history and clinical examination and justified on an individual basis taking due consideration of diagnostic and pre-surgical treatment planning needs and benefits, radiation risk and cost. Effective assessment of proposed implant sites requires that clinicians interpret implant sites for many factors related to successful implant restorations, including adequate bone volumes, distance away from teeth/implants, sufficient prosthetic space for restoration, and precise implant placement. A protocol is proposed on how to do a structured review and read a CBCT data volume to ensure that pathosis or critical anatomical structures are not missed that may impact on, or enhance diagnosis, treatment planning and treatment outcomes.

CBCT is increasingly being accepted as the new professional standard of care in implant dentistry. With this technology, adequately trained clinicians can enhance their practice and best serve the interests of their patients. However, with growing technological and software development and increasing utilization of this indispensible technology, it is important that the dental profession develop evidence-based guidelines and recommendations for its proper and effective use.

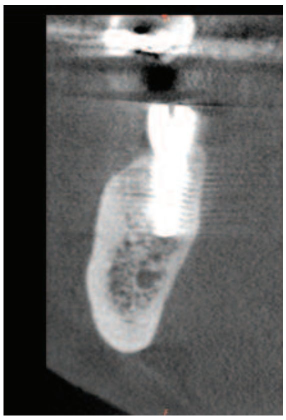


Figure 41: Streaking artefact from dental implant.

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