Cone Beam CT for Pre-Surgical Assessment of Implant Sites

David C. Hatcher, DDS, MSc; Craig Dial, DRT; and Camille Mayorga, DRT

Abstract

The pre-surgical assessment of proposed implant sites requires very specific and accurate data. Imaging has always been used to assist with the implant site assessment but until the recent introduction of cone beam CT scanners, the available imaging had a low value when considering the ratio between diagnostic potential, cost of study, and risk to the patient. CBCT scanners are nearing the end of their first-generation dedicated maxillofacial imaging modalities and have proven to be an extremely useful imaging tool for pre-surgical assessment of implant sites. CBCT scanners are easy to use and produce a 3-D image volume that can be reformatted using software for customized visualization of the anatomy. Protocols have been developed that optimize the visualization of image for implant site assessment.

Anatomic and prosthetic factors are considered by the clinician to determine the best implant placement sites. Implants need to be placed where they have the best chance for success. The implant not only needs to be located in an area of a missing tooth but the implant needs to be placed in a way to satisfy restorative, esthetic, biomechanical and functional requirements (prosthetic considerations). Imaging can be used to determine status of the anatomy in the proposed implant site and how to best optimize the implant placement considering the prosthetic needs and anatomic constraints. An imaging stent can be used to provide detailed feedback relat-



Authors / David C. Hatcher, DDS, MSc, is acting associate professor at the Department of Oral and Maxillofacial Surgery, University of California, San Francisco. He also is in private practice at Diagnostic Digital Imaging, Sacramento.

Craig Dial, DRT, is in private practice at Diagnostic Imaging Center, Sacramento.

Camille Mayorga, DRT, is in private practice at Diagnostic Digital Imaging, Sacramento.

Figure 1. An image volume can be reformatted and displayed in multiple planes using software tools. The patient's anatomy has been reformatted in axial (upper left), sagittal (upper right), coronal (lower left) and transaxial planes (lower right). Selected anatomy has been labeled as follows: Maxillary Sinus (MS), Nasal Fossa (NF), Mental Foramen (MF), Mandibular Canal (MC), Sphenoid Sinus (SS), Incisive Canal (IC) and Hard Palate (HP).

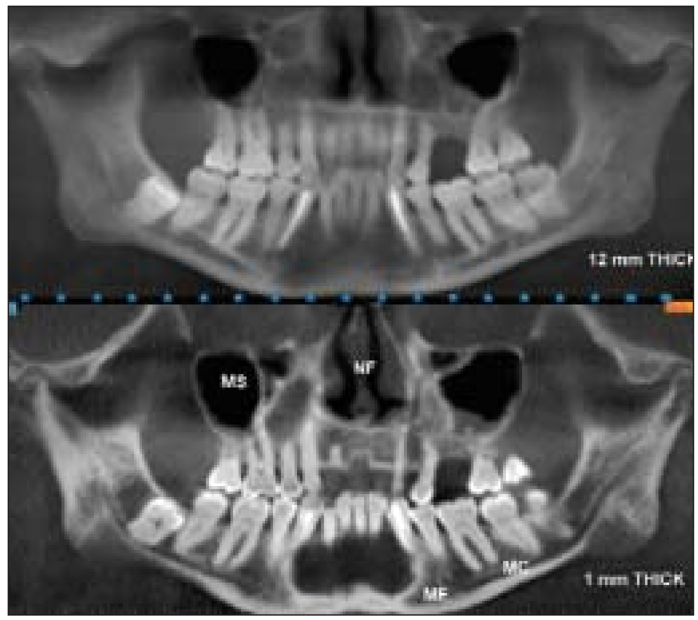

Figure 2. The maxillofacial structures have been reformatted and displayed in curved planes of variable thickness resembling a panoramic view. The upper image is 12 mm thick (buccolingual) and the lower image is 1 mm thick. Selected anatomy has been labeled as follows: Maxillary Sinus (MS), Nasal Fossa (NF), Mental Foramen (MF) and Mandibular Canal (MC).

ing the prosthetic and anatomic considerations. Determining the relationships between the anatomic and prosthetic considerations leads to the development of a set of imaging goals and the methods required for achieving the desired imaging outcome. Ideal imaging studies are the successful fulfillment of goals derived to solve specific clinical problems.

There is a wide spectrum of imaging options requiring a thoughtful strategy to select imaging techniques that produce optimum diagnostic information. The ideal imaging modality produces the desired diagnostic information while minimizing the cost and risk to the patient.

The purpose of this article is to introduce volumetric imaging (cone beam CT) for pre-surgical assessment of implant placement and to compare this technique with other available imaging techniques.

Imaging Goals

General Imaging Goals

Once the implant sites have been determined, then the imaging strategies and goals can be developed. In all cases, the replacement of the missing teeth involves restoring a portion or all of the occlusion and therefore there may be anatomic interests that extend beyond the implant site. This may be an important consideration when determining the imaging strategy. For example, do you want the region of interest extended beyond the implant site to include all components of the articulation, such as the opposing arch, maxillomandibular spatial relationships and temporomandibular joints (TMJs)? Imaging can be used by the clinician to understand the anatomic foundation for placing the implant and restoring the occlusion.

- Image the entire region of interest (ROI)
- View the ROI in at least 2 planes at right angles to each other (3D perspective)

■ Obtain images with maximum detail, minimal distortion and minimal superimposition

■ The diagnostic value of the imaging study must be in balance with the cost and risk associated with obtaining the study.

Implant Site Assessment Imaging Goals

For each implant site, the following anatomic considerations may allow the clinician to determine the best site for the implant and meet the prosthetic goals.

■ Determine bone height and width (bone dimensions).

■ Determine bone quality

■ Determine long axis of alveolar bone

■ Identify and localize internal anatomy

■ Determine jaw boundaries

■ Pathology detection

■ Transfer of radiographic information

Bone Dimensions

Bone height and width allow the clinician to determine how much bone is available in the proposed implant site.

Bone Quality

Dynamic loading of an implant imparts forces to the adjacent bone. There is an assumption that bone density is directly proportional to load-bearing capacity of the bone and that implant failure is associated with low bone density.[8] The architecture of the supporting bone is also a factor associated with the functional capacity of these tissues. Dynamic loads received by the implants may strain the supporting bone and induce changes

Figure a.

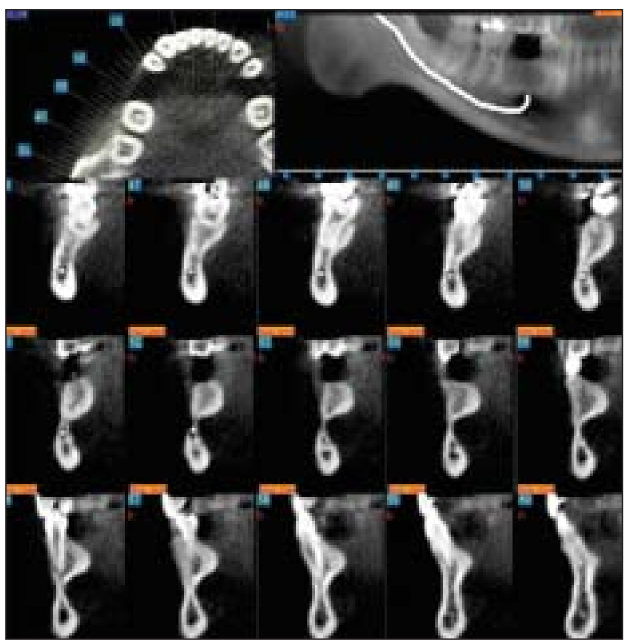

Figure 3b.

Figures 3a–c. These images are for a 25-year-old male with congenitally missing mandibular second bicuspids. The sites are being evaluated for feasibility of implant placement. The clinical photographs show the edentulous sites and suggest the presence of adequate vertical and buccolingual alveolar bone volume to place implants. The CBCT scan reconstructed in 3-D, axially and transaxially, showed a large lingual concavity that would severely limit implant placement.

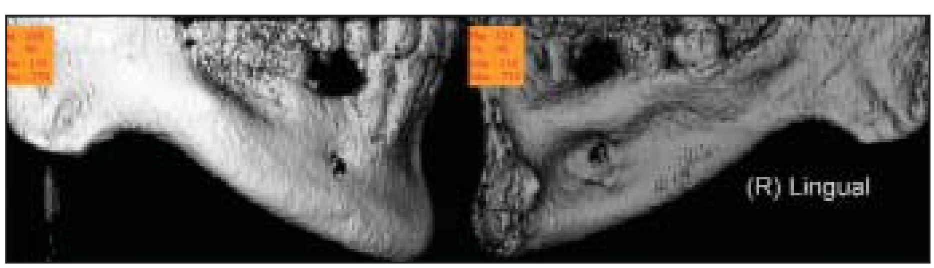

Figure 3c.

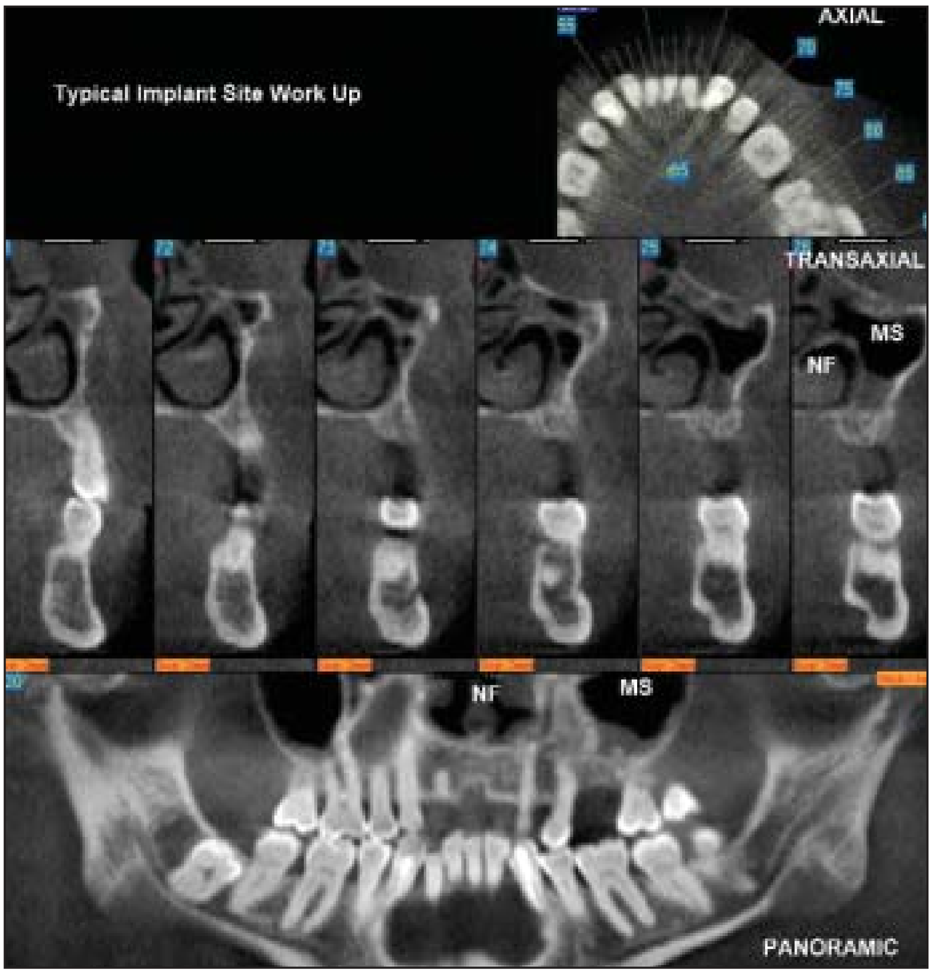

Figure 4. This is an implant site workup for missing tooth #14. The axial projection (upper right) is used to map the jaw curve to create the curved (panoramic projection). The jaw curve is also used to map out the location of the transaxial sections (center panel). The transaxial sections are created perpendicular to a tangent created at the desired point on the jaw curve.

in that bone. Bone requires a certain amount of strain for maintenance, but excessive strain may cause fatigue failure of the trabeculae.

Long Axis of the Alveolar Bone

Axis orientation describes the angle formed by the vertical long axis of the alveolar-basal bone complex when viewed in cross-section. Information about the axis orientation is important for successful alignment of the implant within the boundaries of the jaws. Determining the long axis of the alveolar bone allows the clinician to optimize the trajectory of implant placement with the emergence profile and loading characteristics of the implant (**Figures 1, 3a-c, 4**).

Internal Anatomy

The most common internal anatomy to be identified and localized includes the mandibular canal, maxillary sinus, nasal fossa, mental foramen, incisive canal, and adjacent teeth. Identifying these structures aid the clinician in determining the boundaries for implant placement (**Figures 1, 2, 4**).

Jaw Boundaries

Imaging can be used to identify the outer boundary of the jaws including impressions into the jaws, such as fossae (**Figures 1, 3a-c, 4**).

Pathology Detection

Jaw pathology in the proposed implant site or within the maxillofacial regions is important to detect, diagnose, treatment plan, and treatment sequence. Abnormalities involving the alveolar ridge include retained root tips, inflammatory processes, cyst, and tumors. In addition, anomalies involving other maxillofacial structures such as maxillary sinuses and TMJs may complicate the successful implant process. For example, changes in stress (force/area) directed at poorly adapted TMJs may increase TMJ symptoms. Changes in TMJ stress levels may result from operative manipulations, changes in masticatory abilities and changes in vertical dimension or maxillomandibular spatial relationships (**Figures 5a-d, 7a-d**).

Transfer of Radiographic Information (Communication)

The diagnostic and treatment planning information gained during image analysis may need to be transferred. For example, the restorative dentist may have performed the original image analysis, made decisions about the precise placement location for implants and now wants to convey the information to a surgeon and/or patient. Images and derivative information can be used for downstream communication and knowledge transfer (**Figures 6a-c**).

Imaging Options

Several imaging modalities have been used for the pre-surgical evaluation of implant sites. **Table 1** is a comparison matrix showing the relative value of the commonly available 2- and 3-D imaging modalities.[1-15] The panoramic, periapical and cephalometric images contain superimpositions, have large information voids related to depth, and are affected by projection geometry so that measurements are not reliable. Only tomography, conventional CT scans, and cone beam CT scans provide the information desired about each implant site. When the imaging goals are extended to occlusion, maxillomandibular spatial relationships and

Figure 5a.

Figure 5b.

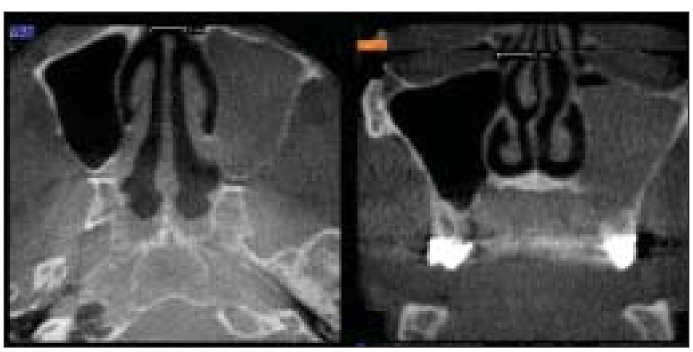

Figure 5c.

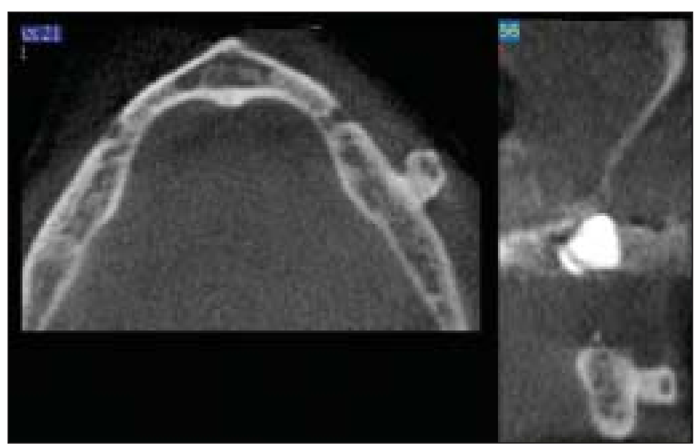

Figure 5d.

Figures 5a–d. This sequence of images was prepared for a 64-year-old male in the planning phase for mandibular posterior implants. A single CBCT scan created the opportunity to evaluate the proposed implant sites and the remainder of the maxillofacial region. In this case, the following relevant information was acquired from the CBCT: left side maxillary sinusitis with an occluded osteomeatal complex, benign tumor (osteoma) extending from the buccal surface of the left side of the mandible, degenerative joint disease involving the left TMJ, over-eruption of the maxillary posterior teeth, and the maxillomandibular spatial relationships.

Table 1

Valuation of Implant Imaging Techniques

Imaging Goal	2D Sources Caphalometric	Tomographic	Panoramic	Periapical	3D Sources CT	Cone Beam CT
Bone height	★	★★★	★★	★★★	★★★★	★★★★
Bone width	–	★★★	–	–	★★★★	★★★★
Long axis or ridge	–	★★★	–	–	★★★★	★★★★
Identify internal anatomy	★	★★★	★★	★★★	★★★★	★★★★
Localize anatomy	★	★★★	★	★	★★★★	★★★★
Determine jaw boundaries	–	★★★	★★	–	★★★★	★★★★
Pathology detection	★	★★	★★★	★★	★★★	★★★
Bone quality	–	★★	★★	★★	★★★★	★★★
Communication	★	★★	★★	★	★★★★	★★★★
Anatomy overview	★★	★	★★	★	★★★	★★★★
Benefit/risk/cost ratio	★	★★★	★★	★	★★★	★★★★

Table 1 shows a list of commonly used imaging techniques and associated imaging goal. The relative application value for each imaging technique has been rated as follows:

– = No Value ★ = Low Value ★★ = Moderate Value ★★★ = High Value ★★★★ = Highest Value

the temporomandibular joint then cone beam CT scans stand alone as the best value.

Volumetric Imaging

Volumetric imaging (VI) or cone beam CT (CBCT) creates the opportunity to extend the information yield beyond the conventional imaging methods and is an ideal modality for implant planning. CBCT produces accurate 3-D image data. The field of view is scalable and one scan can include the entire maxillofacial region including the maxilla, mandible, base of skull and TMJs. Currently, the Newtom 9000 is the only available CBCT unit in the North America and is being distributed by Aperio Services. This unit has a voxel size of approximately 0.3 mm.[3] The small voxel size would allow feature detection size and dimensional accuracy in the range of 0.5 mm. A single cone beam CT scan contains enough information to satisfy the imaging objective stated above including maxillomandibular spatial relationships.

Software is used to display and visualize the anatomy in a way that is clinically meaningful. The software allows for multiplanar reformation and display. The primary reconstruction of the raw data is completed parallel to the occlusal plane and therefore the occlusal plane is used as the visualization reference plane. The reconstructions can occur in the axial, coronal, sagittal, curved, and oblique planes (**Figures 1, 2, 4**). The location, dimensions and thickness of the reconstructions can be varied to achieve the desired results (**Figure 2**). The manufacturers of CBCT scanners offer software that is capable of multiplanar reformations but third-party software is also available to import and manipulate image data that has been exported in a DICOM format. Third-party software includes Materialise Simplant and Nemotec Dental Systems.

Summary

The introduction of cone beam CT creates the opportunity for clinicians to acquire the highest quality of diagnostic images with an absorbed dose that is comparable to other dental surveys and less than a conventional CT.[16] The large field of view and 3-D image set offered by CBCT creates the opportunity for the clinician to adequately assess the implant site, look at the opposing occlusion, TMJs, and other factors that may associated with the total success of implant-based rehabilitation of the patient's occlusion (**Figures 5a-d, 7a-d**).

The next generation CBCT scanners available by the first quarter of 2004 will have improved capabilities that include a reduction in voxel size from 0.3 to 0.1 mm,[3] increased number of gray levels from 256 to 4096 shades, faster scan times down to 10 seconds, and larger field of view up to 9-inch diameter. The proposed improvements will increase the image quality, diagnostic potential, and increase the value of the study to the patient and clinician (**Figure 8**).

CBCT first became available in the United States in May 2001 and the number of CBCT scanners in California exceeds the combined total for the remainder of the states. Most of the CBCT scanners are located in universities and dental imaging centers, and are available by referral to the dental community. **CDA**

Figure 6a.

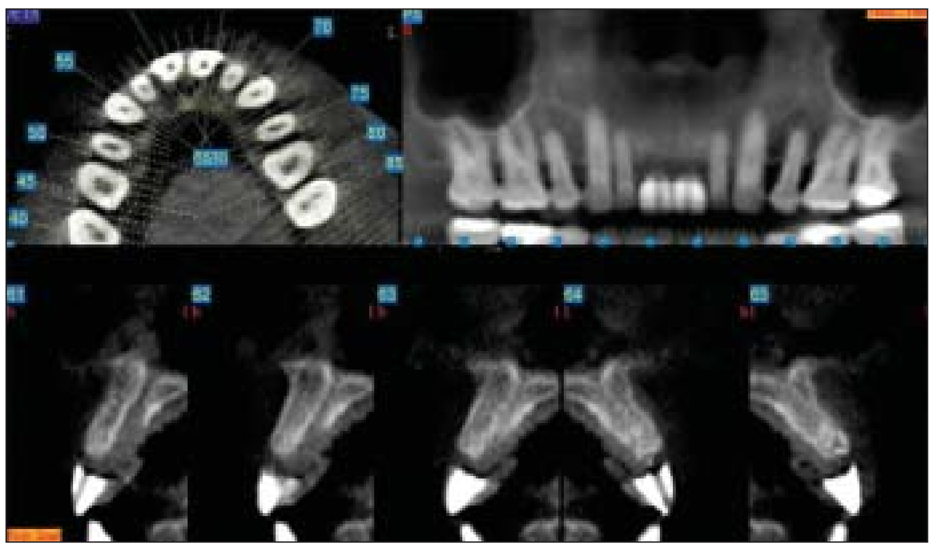

Figure 6b.

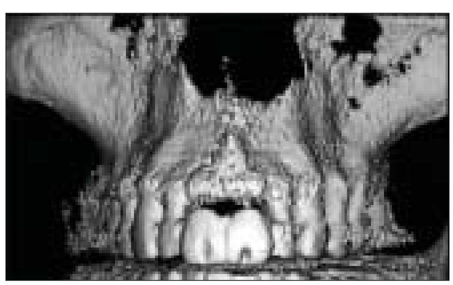

Figure 6c.

Figures 6a–c. A 56-year-old male missing teeth #s 8 and 9 had a CBCT scan with a radiographic stent in place. Opaque teeth were fabricated and positioned to simulate their desired final size and position. A hole drilled down the long axis of the teeth identifies the trajectory of the implant placement and to serve as surgical guides. The stent can be used as a reference for radiographic planning and to transfer the simulation product to the mouth.

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Figure 7a.

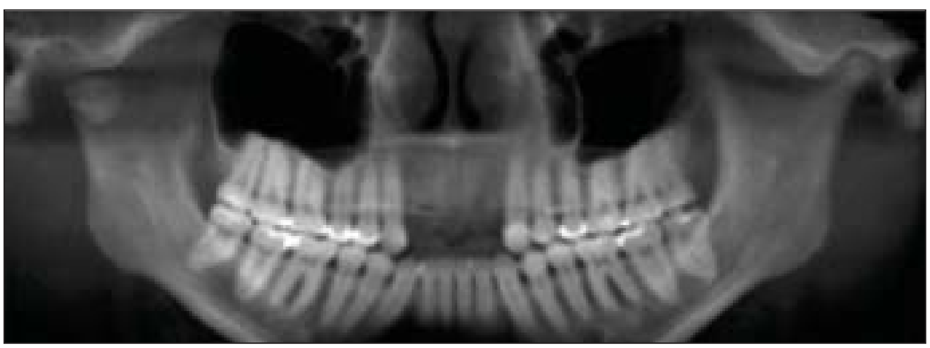

Figure 7b.

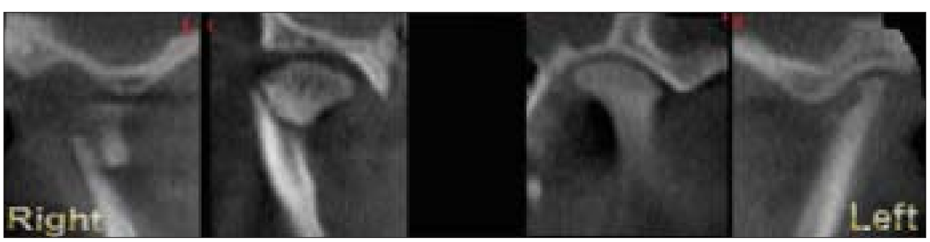

Figure 7c.

Figures 7a–d. This series of images belong to a 19-year-old female who traumatically lost teeth #s 7-10. A typical implant work up would be isolated to the implant site (axial, transaxial, panoramic views) and allow for determination of the bone height, width, and quality. With CBCT there is more information available including the opposing occlusion and the TMJs. Evaluation of the TMJs showed left side degenerative joint disease and a right side sub-condylar fracture dislocation.

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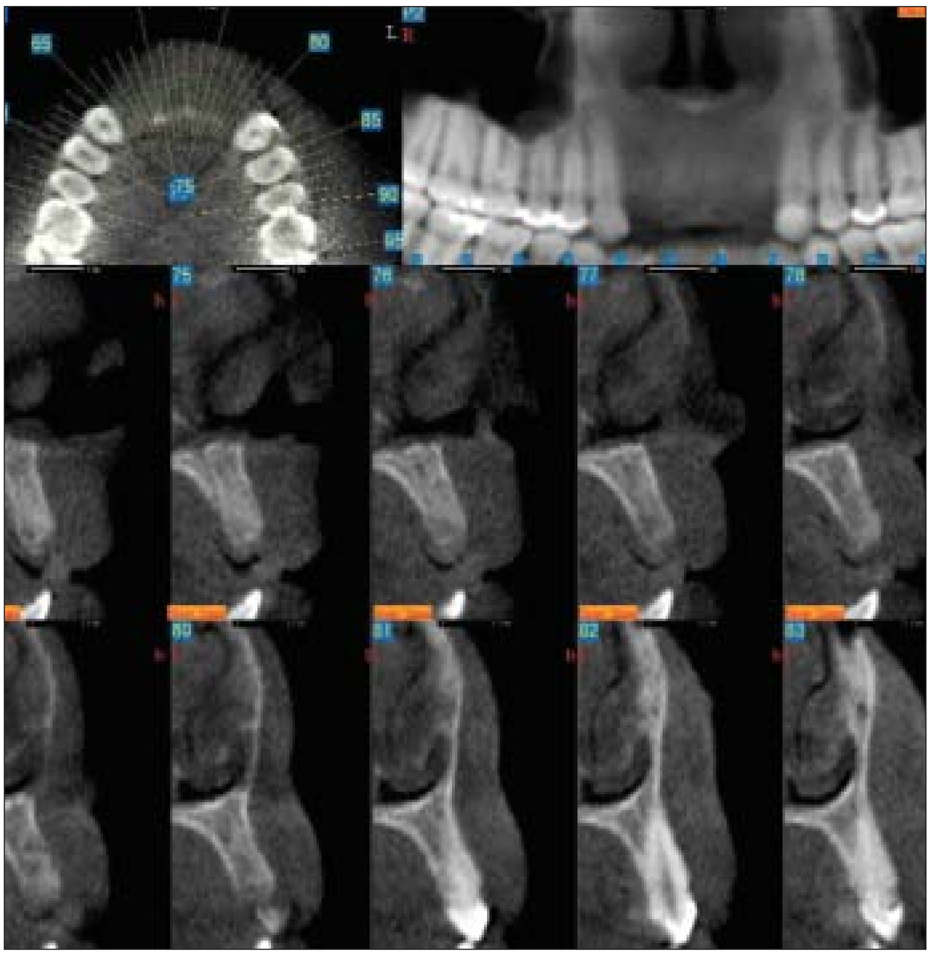

Figure 7d.

Figure 8: Newtom 9000 Plus, next-generation CBCT, showing a larger field of view, facial soft tissue, and orthographic cephalometric rendering.