

10-1-2015

Imaging of the Jaws

Lisa J. Koenig

Marquette University, lisa.koenig@marquette.edu

Accepted version. *Seminars in Ultrasound, CT and MRI*, Vol. 36, No. 5 (October 2015): 407-414.

[DOI](#). © 2015 Elsevier Inc. Used with permission.

NOTICE: this is the author's version of a work that was accepted for publication in *Seminars in Ultrasound, CT and MRI*. Changes resulting from the publishing process, such as peer review, editing, corrections, structural formatting, and other quality control mechanisms may not be reflected in this document. Changes may have been made to this work since it was submitted for publication. A definitive version was subsequently published in *Seminars in Ultrasound, CT and MRI*, Vol. 36, No. 5 (October 2015): 407-414. [DOI](#).

Imaging of the Jaws

Lisa J. Koenig

*School of Dentistry, Oral Medicine and Oral Radiology,
Marquette University,
Milwaukee, WI*

Introduction

The mainstay of dental imaging has traditionally been the intraoral images called periapicals and bitewings, which for many years were made with film that was wrapped in a protective packet. Today these images are taken using small detectors or sensors that are placed inside the patient's mouth. The first digital intraoral solid-state detector, a charge-coupled device (CCD), was introduced in 1997.¹ These detectors are directly attached to the computer by a wire and give an almost instantaneous image on the computer monitor (Fig. 1). This provides huge savings in time compared with the traditional wet processing needed for films as well as for the ability to manipulate the image and change its brightness and contrast. In addition, because the images appear on a monitor within the operatory it allows for instant feedback to the operator and also the patient. Several manufacturers are now using complementary metal oxide semiconductor technology for their detectors, as it is less expensive to produce than CCD technology.² In dentistry these types of detectors are often referred to as "sensors" to differentiate them from an alternate digital intraoral detector, photostimulable phosphor (PSP) plates. PSP plates are

thinner and more flexible than the solid-state sensors and are often tolerated better by the patient. They are the same size as traditional intraoral film packets and can be used with the same positioning devices without modification. Exposure to x-rays produces a latent image within the plate in the form of stored energy, which is released when the plates are "processed" by laser light in the manufacturer's scanning device or reader. The readers are often small enough that they can be placed in the dental operatory (Fig. 2). The image, therefore, like film is not instantaneous as this is a 2-step process. However, once placed in the reader the images can appear on the computer monitor in as little as 3 seconds. Some dental offices still use film-based imaging but those dentists who have opted to go digital have a choice of using either solid-state sensors (CCD, complementary metal oxide semiconductor) or PSP detectors and some offices have a combination of both systems.

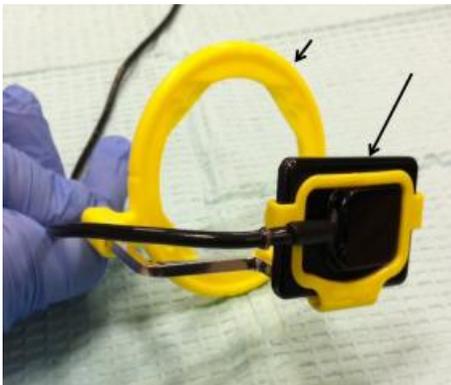


Figure 1. A typical intraoral sensor (long arrow) (Schick by Sirona, Long Island City, NY) is seen in its custom-positioning device (short arrow) (Dentsply Rinn, York, PA), which aids in placement in the mouth. (Color version of figure is available online.)

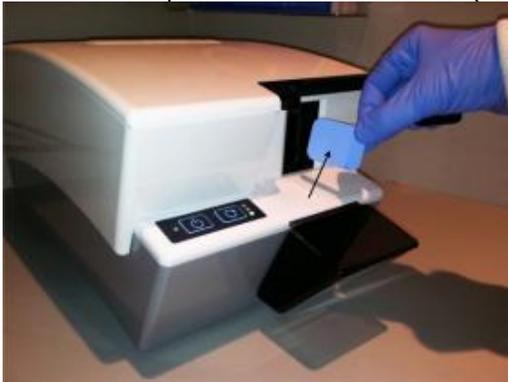


Figure 2. A PSP plate (arrow) is placed in the manufacturer's reader (Digora Optime, Soredex, Tuusula, Finland). The reader is compact enough that it can be placed chairside. (Color version of figure is available online.)

Pertinent Tooth Anatomy

A brief review of pertinent anatomy is helpful for a more complete understanding of the material that follows. Further detail of the anatomy can be obtained in Vahe et al.³ The adult dentition consists of 32 permanent teeth: 3 molars, 2 premolars (bicuspid), 1 canine (cuspid), and a lateral and a central incisor in each of the 4 quadrants. A tooth is made up of a crown and a root. The size and shape of the crown and the number of roots vary depending on the type of tooth. For instance, maxillary molars have 3 roots whereas a central incisor has only 1 root. Teeth have different functions. Molar crowns are larger with bigger surfaces for grinding. Incisor teeth have a thin "incisal" edge to their crowns for shearing.

The crown is covered by dense radiopaque enamel, which is approximately 96% mineralized and the hardest structure the body produces.⁴ It is designed to protect the tooth from occlusal forces and also from the potential hostile environment of the oral cavity. Under the enamel is the slightly less radiopaque dentin, which forms the bulk of the hard tissue of the tooth including crown and root. The dentin in the root is covered by a thin layer of cementum. This layer is less mineralized than enamel and susceptible to loss once the root of a tooth is exposed to the oral environment as in periodontal disease (loss of bone around the tooth root). It is not visible as a separate structure radiographically because it is so thin and also so similarly mineralized as dentin. Cementum is approximately 65% mineralized compared with dentin, which is approximately 70% mineralized.⁴

The enamel and dentin meet in the crown of the tooth at the dentinoenamel junction (DEJ) and this is an important landmark in caries (decay) detection (Fig. 3). Early or incipient interproximal (between teeth) caries is seen only in the enamel, which offers significant resistance due to its high mineralization. Once the caries reaches the DEJ and enters the dentin there is less resistance. The dentinal tubules offer a pathway for progression to the pulp chamber. The pulp chamber is located inside each tooth crown and provides nutrients to the tooth. It contains blood vessels and nerves, which enter the tooth through a foramen at the apex of the root. The nerves and vessels then course through the root in the root canal to the pulp

chamber in the crown. The root canal and pulp chamber appear radiographically as a relative radiolucency compared with the radiopaque dentin (Fig. 3). The pulp can become inflamed if caries reaches the dentin (toothache).

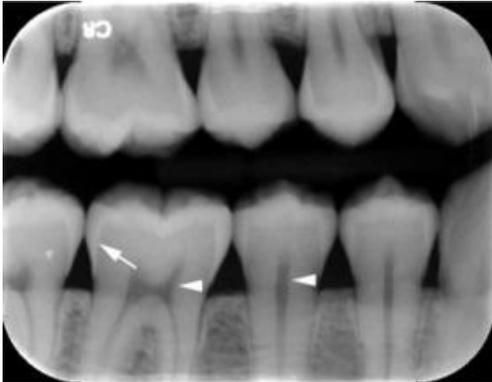


Figure 3. Well-positioned right premolar bitewing radiograph shows both maxillary and mandibular crowns and interproximal spaces between teeth to allow for early caries detection. Arrow shows the clear delineation between the more radiopaque enamel and less radiopaque dentin known as the dentinoenamel junction. The pulp chamber (left arrowhead) and root canal (right arrowhead) are seen as radiolucencies at the center of the teeth.

The tooth root is supported in the bony socket by the periodontal ligament and this appears on the radiographs as a thin radiolucent line surrounding the entire root. The cortical lining of the socket is known as the lamina dura and appears in images as a thin radiopaque line peripheral to the radiolucent periodontal ligament. It surrounds the entire socket and also extends between the cervical portions of the teeth, where it is known as the crestal lamina dura or alveolar crest. The crestal lamina dura is an important landmark in determining loss of alveolar bone, which occurs in periodontal disease. The apical lamina dura, which surrounds the root apex, is an important landmark in determining the origin of lesions at the root apex (Figure 4 and Figure 5).

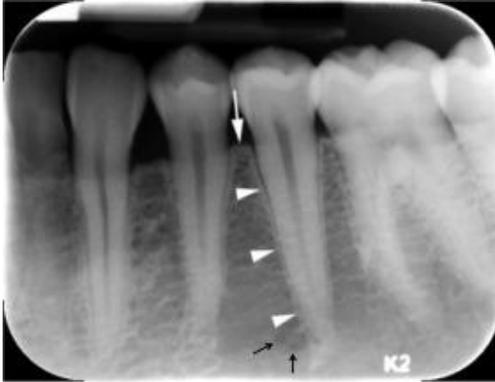


Figure 4. This periapical radiograph of the left mandibular premolar area shows the lamina dura as a thin white line that surrounds the tooth socket (arrowheads). Between the lamina dura and the tooth root is a thin radiolucent line known as the periodontal ligament space. The apical lamina dura (portion around root apex) can be seen intact through a radiolucency (black arrows) to the left of the root apex, confirming that this is not pulpal periapical inflammatory disease but in fact the normal mental foramen. The crestal lamina dura (white arrow) marks the normal height of the alveolar bone. In periodontal disease the crestal lamina dura is lost.



Figure 5. Right maxillary periapical radiograph shows anterior tooth-colored restorations (dental resin composite) on the canine and lateral incisor (arrowheads). The restorations are radiopaque but not as radiopaque as the amalgam restoration on the first molar (long arrow). Note the intact apical lamina dura on the lateral incisor, which appears as a continuous thin radiopaque line around the apex of the tooth (short arrows).

Intraoral Images

A full mouth series of intraoral radiographs consists of 4 bitewing views and periapical views of the maxilla and mandible, which can vary in number from 14-18 views.

Bitewing Views

Bitewing views, as the name infers, are taken with the teeth biting together or in occlusion as referred to in dentistry. Both a molar and a premolar bitewing are taken on the right and left (4 bitewings). Positioning devices or holders allow the detector to cover the maxillary and mandibular crowns of the teeth as well as the crestal alveolar bone between the teeth on each image. Correct positioning of these images is crucial to allow for visualization of the contacts between the teeth (Fig. 3). This is important because the outer edge of the enamel at the contact point is where decay, known as interproximal caries, begins. Because caries causes demineralization of the tooth it presents as a radiolucency within the radiopaque enamel. Interproximal caries begins just below or at the contact point between 2 teeth and in the early stages cannot be visualized clinically in posterior teeth. Hence bitewing views are necessary to detect early lesions known as incipient caries in the premolars and molars (Fig. 6). The use of bitewing images increases the detection of interproximal caries by 85%.⁵ Interproximal caries progresses through enamel in a triangular shape with its broad base at the outer edge of the enamel and its apex directed toward the DEJ. Caries that is still in the outer one-half of the enamel is known as incipient caries. Once the caries has reached the DEJ it spreads along the inner surface of the DEJ, creating a broad base at the outer edge of the dentin. The caries then progresses in a triangular pattern again toward the pulp chamber. Caries that has extended more than halfway between the DEJ and the pulp chamber is known as severe caries. Caries can occur on other surfaces of the teeth, including the biting surfaces, where it is known as occlusal caries. This type of caries can be detected clinically and can be seen only radiographically when it has already reached the dentin.



Figure 6. This left premolar bitewing radiograph shows incipient caries on the distal (posterior) of tooth 20 (arrow) just below the contact point. A triangular radiolucency with its broad base at the outer edge of the enamel is seen within the enamel but does not extend to the DEJ. A lesion that has extended to the DEJ is seen on the mesial (anterior) of tooth 13 (arrowhead). Carious lesions in various stages are also present on several other teeth.

When a dentist detects caries within a tooth, and if the caries is extensive, an assessment has to be made as to whether the pulp has become involved. Several clinical tests may be performed, including vitality tests to determine if the tooth is still viable. Dentists use cold, heat, or an electric pulp tester to compare the response of the tooth in question to that of adjacent teeth. A negative vitality test informs the dentist that the pulp (neurovascular bundle) has been damaged irreversibly and hence before restoring the tooth the pulp needs to be removed. This procedure is known as endodontic therapy or a “root canal procedure.” After endodontic therapy, the normally radiolucent root canal appears radiopaque on images, because the treated root canal is filled with a radiopaque material (Fig. 7).

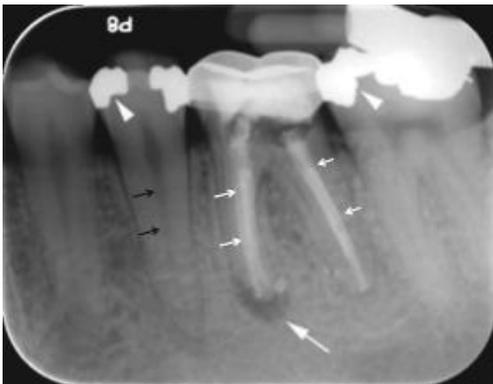


Figure 7. Periapical radiograph illustrating a periapical radiolucency (long arrow) involving a mandibular molar that has undergone root canal therapy. Note that the apical lamina dura is missing. The root canals are filled with gutta percha (short white

arrows), which is radiopaque but not as radiopaque as amalgam restorations in crowns of adjacent teeth (arrowheads). Compare to adjacent tooth with normal radiolucent root canal (black arrows).

Restorations vary, but amalgam restorations have been historically the choice for posterior teeth as they offer resistance to biting forces and a good long-term prognosis. Amalgam-restorative materials, as the name implies, are a composite of mercury, silver, and tin and are sometimes called "silver fillings" because of their appearance. The metallic components of amalgam cause complete attenuation of the x-ray beam and amalgam restorations appear as an image void or complete radiopacity. Gold and high-noble replacement crowns also similarly attenuate the x-ray beam and appear completely radiopaque. Metallic restorations cause significant streaking artifact on computed tomography (CT) scans and can confound interpretation. Tooth-colored restorative materials, known as dental resin composite, were historically used only in anterior teeth but are now frequently used also in posterior teeth. They usually contain a radiopaque filler, so they can be seen on the radiograph (Fig. 7). They are, however, less dense and so not as radiopaque as amalgams or gold crowns, and do not create the same artifact on CT scans.

Periapical Views

A periapical radiograph shows the view of the whole tooth including 2-3 mm of bone surrounding the apex of the root and is limited to teeth in 1 arch. This is in contrast with the bitewing view, which shows the crowns of both the maxillary and mandibular teeth together and does not show the root apices. A dentist may order from 14-18 periapical views depending on his/her preference and the patient's needs.

Periapical radiographs are taken to rule out lesions at the apex of the tooth, which may occur when the tooth has become nonvital. Death of the pulp results in degradation products that exit the tooth through the apex and set up an inflammatory response. This causes loss of apical bone and results in a periapical radiolucency (Fig. 7). The apical lamina dura, which normally appears as a thin radiopaque line, is also lost (compare Fig. 5 with Fig. 7). The presence of a radiolucency at the apex of a nonvital tooth automatically implies

pulpal periapical inflammatory disease and only 2 options remain for the tooth: extraction or root canal therapy. The dentist determines which option is better for the tooth based primarily on restorability, that is, whether the tooth and root can be restored to optimal form and function. When a root canal therapy is performed the infected pulp is removed and the canal or canals, depending on the tooth, are cleaned and debrided⁶ (Fig. 10). The canals are then filled with root-filling material, usually a rubber type material called gutta percha (Fig. 7). This appears radiographically as a radiopacity but is not as radiopaque as amalgam.



Figure 8. Periapical radiograph shows radiolucencies (arrowheads) at the apices of vital mandibular anterior teeth representing early lesions of periapical cemental dysplasia.



Figure 9. Periapical radiograph shows a more mature stage of periapical cemental dysplasia. As the lesions mature, radiopacities are seen within radiolucencies (large arrow), which helps to distinguish this lesion from pulpal periapical inflammatory disease.

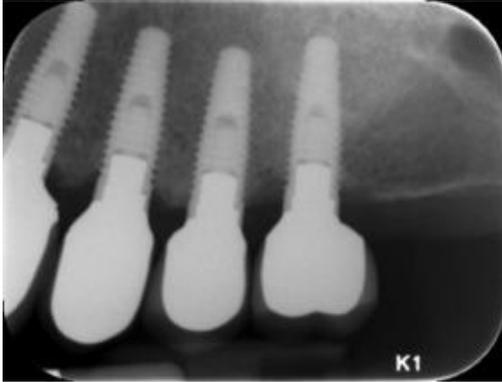


Figure 10. Periapical radiograph shows 4 implants in the left maxilla with osseointegration as evidenced by the bone engaging the threads of the implant and lack of any peri-implant radiolucency. The periapical radiograph is the imaging modality of choice for postoperative evaluation of implants.

Vitality of the tooth is important as other lesions may appear as radiolucencies at the apex of teeth, most notably a condition called periapical cemental dysplasia (Fig. 8). This condition commonly occurs in middle-aged African American females and presents as a periapical radiolucency in the early stages of the disease. As the lesion matures, radiopacities representing dysplastic cementum are deposited within the radiolucency, making it less likely that it would be misdiagnosed as pulpal periapical inflammatory disease (Fig. 9). The teeth in periapical cemental dysplasia are vital and this condition is benign and requires no treatment.

Although periapical images are not adequate for preoperative implant planning, they are the image of choice for determining osseointegration of implants postoperatively (Fig. 10). Implants cause beam-hardening artifact on cone-beam CT (CBCT) scans, which precludes the use of this technology for postoperative implant evaluation. Periapical radiographs may also demonstrate other pathologies that occur in the alveolar bone, including common odontogenic lesions such as odontomas and dentigerous cysts. If the periapical image is not able to visualize the full extent of the lesion then the dentist may opt to take a panoramic radiograph, a CBCT scan, or a conventional medical CT scan.

Panoramic Radiographs

Panoramic radiographs allow visualization of both the maxilla and mandible and the surrounding oral and maxillofacial structures, including the temporomandibular joints (Fig. 11). Panoramic radiographs are extraoral images as the image receptor and x-ray source rotate synchronously around the patient's head. The machine uses a slit collimator and images are built up in thin slices. Receptors are larger versions of the intraoral digital sensors, being usually a CCD sensor or a PSP plate. Machines with CCD sensors display the image as acquired. PSP plates require "processing" in the manufacturer's reader, like intraoral plates. The patient either stands or sits within the machine and bites on a registration peg. Laser light or other positioning devices assist in placing the patient accurately within the machine's focal trough. This is the area between the image receptor and x-ray source where objects are imaged and in focus. A panoramic radiograph is commonly taken to evaluate third molars or extensive pathology that cannot be fully visualized on smaller intraoral periapical radiographs. The panoramic image also allows for visualization of teeth and pathology in relation to critical structures such as the mandibular canal and maxillary sinuses. However, owing to the 2-dimensional nature of the image the panoramic radiograph has significant limitations, including distortion, which precludes accurate measurements. Pathology cannot be evaluated in the buccal-lingual dimension (jaw thickness) and there is inherent magnification and overlapping of teeth in the technique, which varies depending on the machine. Many oral surgeons now prefer to take a CBCT image so that the pathology can be evaluated in 3 dimensions and the exact location of the lesion to vital structures such as the mandibular neurovascular bundle can be determined.



Figure 11. A panoramic radiograph shows the maxilla and mandible and surrounding maxillofacial structures, including the temporomandibular joints. Note the impacted displaced right mandibular canine close to the inferior border of the mandible (arrows).

Cone-Beam Computed Tomography

The introduction of CBCT machines into the USA in the early 2000s revolutionized dental radiology. CBCT allows for 3-dimensional images of the oral and maxillofacial area, similar in appearance to images from conventional CT, but at a significant dose savings.^{7 and 8} In addition, the cost of the machine is significantly less than that of a conventional CT scanner and is therefore often affordable for dentists to place in their office. CBCT and medical CT images are acquired in different ways. There are 2 types of image receptor: flat panel and image intensifier. Most CBCT units currently use a flat panel detector comprising a large-area solid-state sensor. The units have a circular collimator; consequently the x-ray beam is cone shaped, hence the name cone beam.⁹ The x-ray source and image receptor rotate around the patient in a similar fashion to that of panoramic machines; however, the images acquired are similar to cephalometric images, which are large 2-dimensional lateral views of the head. The machine may rotate 360° around the patient in acquiring these images, called basis images. The x-ray beam is usually pulsed to reduce radiation exposure. The basis images are reconstructed into a volume and presented on a typical section screen as axial, sagittal, and coronal images. Most software programs also allow for viewing of 3D images without additional reformatting. Reconstruction time varies depending on the field of view and resolution selected.

There are a significant number of CBCT machines on the market targeted to the various dental specialties, each varying in the size and number of fields of view offered, and with options to have the patient sitting, standing, or supine. Smaller fields of view in the 5 cm × 5 cm range are usually used for endodontic applications as they generally provide a higher resolution, which is needed for visualization of additional root canals or fractures within the root of the tooth. Fields of view can vary from these very small volumes to extra-large volumes in the range of 24 cm × 17 cm, which are indicated for cephalometric analysis or cephalometric surgical planning. Images acquired with CBCT machines are similar to bone-window images in traditional medical CT imaging and therefore inadequate for evaluating soft tissue. Resolution is higher with isotropic voxel sizes in some of the newer machines as small as 0.05 mm. The radiologist is responsible for determining the optimal field of view and resolution using the principle of As Low As Reasonably Achievable (ALARA), meaning radiation dose should be the minimum possible for the required diagnostic task.

The most common application of CBCT in dentistry is for implant planning. This is because it establishes the exact height, width, and contour of the alveolar ridge and the precise location of vital structures such as the maxillary sinuses and mandibular canal, all information necessary for safe implant placement.

Panoramic radiography is limited by its inability to generate cross-sectional images. Thus, when panoramic radiographs appear to demonstrate adequate bone for implant placement in the vertical dimension, the dentist usually obtains cross-sectional imaging with either conventional CT or CBCT to evaluate adequacy of bone in the buccal-lingual dimension and to obtain direct measurements of the prospective implant site(s).¹⁰

In 2012, the American Academy of Oral and Maxillofacial Radiology (AAOMR) published its position paper on the selection criteria for the use of radiology in dental implant planning.¹¹ The AAOMR concluded that panoramic radiography is considered unsuitable as a single imaging source for dental implant assessment. Furthermore, the AAOMR recommended that cross-sectional imaging

be used for the assessment of all dental implant sites and that CBCT is the imaging method of choice for obtaining that information.

The radiologist determines the buccal-lingual width of the alveolar bone using the measuring tools in the CBCT imaging software. The distance of vital structures to the implant site is critical in determining whether sufficient bone is available for implant placement. Dentists often fabricate radiographic guides that help determine the ideal location and angulation for the implant. These guides, which are worn during the scan, may be full-coverage denture-like guides fabricated of radiopaque material (Fig. 12A) or localized guides that use radiopaque markers to indicate the ideal position of the implant. The radiologist can then measure the height and width of the alveolar bone in the precisely desired location of the implant. Of consideration would be the proximity to vital structures such as the nasopalatine canal, floor of the nasal cavity, inferior alveolar neurovascular bundle, maxillary sinuses, etc. In the mandible, the width of the alveolar bone is typically measured both at the alveolar crest and at the superior border of the mandibular canal. Estimation of the available mandibular bone height for implant placement is then the measurement between these 2 points (Fig. 12B). Mesial to the mental foramen, where the mandibular canal ends, the height is measured from the alveolar crest to the bottom of the mandible. In the maxilla, the height is measured from the alveolar crest to the maxillary sinus. Dentists may also need to know the proximity of the adjacent teeth crowns and roots to determine whether sufficient space is available to restore the implant with the prosthesis once the implant is in place. If ample room is not available, orthodontics may be required to move teeth before implant surgery.

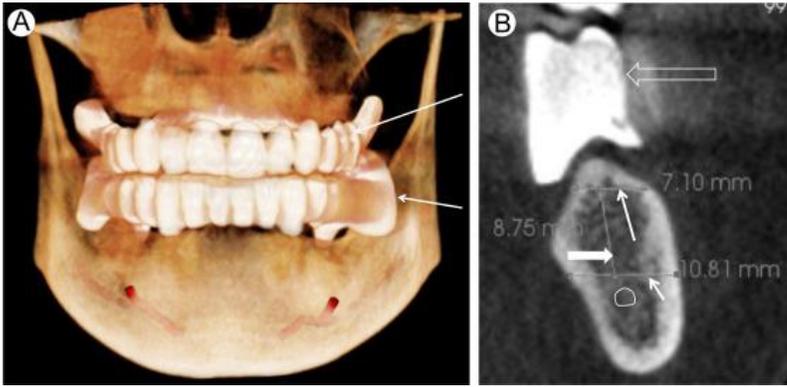


Figure 12. (A) 3D CBCT volume rendering. Patient is edentulous and wearing maxillary and mandibular radiopaque radiographic guides (arrows) made of temporary crown and bridge material (Integrity, Dentsply Caulk, Milford, DE). (B) Left mandibular cross-sectional CBCT image in the same patient shows the radiopaque guide (hollow bold arrow) at the first molar site straddling the mandibular ridge. Measurements of width are typically made at the superior border of the mandibular canal (short thin arrow) and the alveolar crest (long thin arrow). The bone height between these points (solid bold arrow) is also measured. Mandibular canal (white circle). (Color version of figure is available online.)

Surgical guides can be fabricated from the CBCT data and help the surgeon exactly place the implant in the desired location. This usually requires the CBCT data to be exported as DICOM files into third-party implant-planning software such as Simplant, NobelGuide, and Anatomage. The implant planning software merges 2 or 3 data sets depending on the program. In the Simplant program the patient is scanned wearing the radiographic guide and then the radiographic guide is scanned separately. In the Anatomage system the patient is scanned separately and then stone models derived from impressions of the patient are used by the dentist for prosthetic treatment planning. The models are scanned both before and after the treatment planning. Models are made by first taking an impression of the patient's arch, either maxilla or mandible, and then pouring up the impression with stone. The stone model, therefore, is a replica of the patient's maxilla or mandible including the soft tissue. By merging the scans, the implant planning software is able to accurately assess the ideal position of the implant relative to the available bone and the desired occlusion of the restored implant. Implant planning software programs have libraries of the various different types of implants and the desired shape, length, and width of the implant can be determined before surgery. This is accomplished by selecting a "virtual" implant from the

library, superimposing it on the scan, and adjusting its size and shape to fit the patient¹². Once the correct virtual implant has been chosen and the exact angulation determined the data can then be exported for fabrication of the surgical guide. Surgical guides may contain just "pilot drill" holes, which allow for angulation of the initial pilot drill only and not subsequent drill sequences (Fig. 13). Alternatively, the guide may contain "master sleeves," which allow for guidance of every drill by the use of insert tools. The insert tools allow for guidance from the initial pilot drill through subsequent drills with gradually increasing diameters until the final desired diameter of the implant is reached.¹³ The use of surgical guides improves predictability of outcomes. If an implant is placed by free hand there is a risk of violating critical structures or placing the implant outside the confines of the alveolar bone (Fig. 14).



Figure 13. A typical maxillary surgical guide made with the Anatomage implant planning software. Pilot drill hole is seen on patient's right (arrowhead) and a master sleeve that allows insert tools is on the left (arrow). (Courtesy: T. Hart, DDS.) (Color version of figure is available online.)

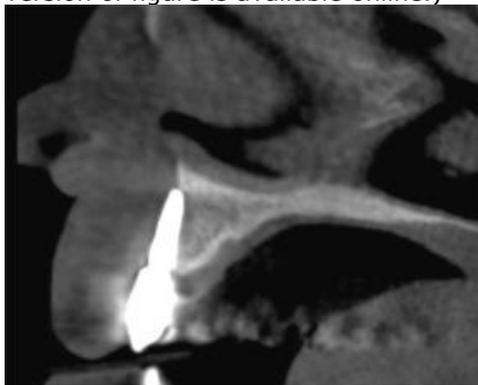


Figure 14. A sagittal CBCT view of the right anterior maxilla shows that the implant at the lateral incisor site has been placed too far facially and is out of the confines of the maxillary alveolar bone.

In addition to CBCT there are several commercially available dental CT reformatting programs such as DentaScan (GE Medical System, Global Center, Milwaukee, WI) that are useful for imaging the teeth and jaw.

Conventional CT With Dental Reformatting Programs

Conventional medical CT imaging using reformatting software programs is also useful and frequently used for evaluating the teeth and jaws. The patient is placed supine in the CT gantry and may be secured using a head holder, chin strap, and sponges on either side of the head to prevent motion during the scan. A digital scout view is obtained to define the upper and lower boundaries of the scan and to ensure that the scan plane is parallel to the alveolar ridge.

Thin axial images are then acquired and the technologist selects one that ideally demonstrates the full contour of the mandible or maxilla and that is at the level of the roots of the teeth. Using this reference image, the technologist deposits the cursor in multiple positions along the curve of the mandible or maxilla. The CT software program then automatically connects these points, producing a smooth curved line, which defines the plane and location of a series of reformatted panoramic images produced buccal and lingual to the line. The program then places a series of numbered lines perpendicular to this curved line. The perpendicular lines are defined where multiple oblique sagittal (cross-sectional) images would be automatically reformatted. A 2-mm space is customarily used between reformatted cross-sectional images; however, this can be adjusted by the technologist. These reformatted images have the benefit of not being degraded by streak artifact as the artifact projects at the level of the crowns of the teeth and not over the area of interest, the bone and roots. When complete, 3 types of images are displayed: axial, oblique sagittal (cross-sectional), and panoramic. The DentaScan panoramic images are free from superimposition of other osseous structures, unlike standard panoramic radiographs. The oblique sagittal views are unique and allow clear identification of buccal and lingual cortical margins and buccolingual width, as well as normal anatomical structures such as the inferior alveolar canal, mental foramen,

mandibular foramen, genial tubercle, greater and lesser palatine foramen, incisive canal, and maxillary sinus. In a typical study, 30-50 axial images, 40-100 cross-sectional images, and 5 panoramic images are generated.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is not typically used for implant planning. The primary indication for MRI is the evaluation of tumors and lesions of the jaw or for soft tissue lesions. It may also be used for evaluating the temporomandibular joint. T1 images are useful for determining marrow replacement by tumor. Conventional medical CT may also be used. Cone-beam CT uses a bone setting and cannot characterize soft-tissue findings.

References

- ¹ G.C. Sanderick, D.A. Miles. Intraoral detectors. CCD, CMOS, TFT, and other devices. *Dent Clin North Am*, 44 (2) (2000), pp. 249–255
- ² J.B. Ludlow, A. Mol. Digital imaging. S.C. White, M.J. Pharoah (Eds.), *Oral Radiology: Principles and Interpretation* (ed 6.), Mosby, St. Louis, MO (2009), p. 80
- ³ Vahe M. Zohrabian, Colin S. Poon, James J. Abrahams. Embryology and anatomy of the jaw and dentition. *Semin Ultrasound CT MR*, 36 (5) (2015), pp. 397–406
- ⁴ M. Bath-Balogh, M.J. Fehrenbach. *Dental Embryology, Histology and Anatomy*. Elsevier Saunders, St Louis, MO (2006)
- ⁵ B.F. Hansen. Clinical and roentgenologic caries detection. *Dentomaxillofac Radiol*, 9 (1980), p. 34
- ⁶ Vahe M. Zohrabian, James J. Abrahams. Inflammatory diseases of the teeth and jaws. *Semin Ultrasound CT MR*, 36 (5) (2015), pp. 434–443
- ⁷ J. Mah, R. Danforth, D. Hatcher. Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*, 96 (2003), pp. 508–513
- ⁸ J.B. Ludlow, M. Ivanovic. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*, 106 (2008), pp. 930–938
- ⁹ W.C. Scarfe, A.G. Farman. Cone-beam computed tomography. S.C. White, M.J. Pharoah (Eds.), *Oral Radiology: Principles and Interpretation* (ed 6.), Mosby, St. Louis, MO (2009), p. 225

- ¹⁰ C.C. Wyatt, M.J. Pharoah. Imaging techniques and image interpretation for dental implant treatment. *Int J Prosthodont*, 11 (5) (1998), pp. 442–452
- ¹¹ D.A. Tyndall, J.B. Price, S. Tetradis, *et al.* Position statement of the American Academy of Oral and Maxillofacial Radiology on selection criteria for the use of radiology in dental implantology with emphasis on cone-beam computed tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol*, 113 (2012), pp. 817–826
- ¹² Vahe M. Zohrabian, Michael Sonick, Debby Hwang, James J. Abrahams. Dental implants. *Semin Ultrasound CT MR* (2015) [in this issue].
- ¹³ Chenin DL: Surgical guides. In: Tamimi DF (ed): *Specialty Imaging: Dental Implants*. Salt Lake City, UT: Amirsys 3:39,2014.

About the Author:

Address reprint requests to Lisa J. Koenig, BChD, DDS, MS, Oral Medicine and Oral Radiology, Marquette University School of Dentistry, PO Box 1881, Milwaukee, WI 53201-1881.