Implant Imaging for the Dentist

• **Muralidhar Mupparapu,** DMD •
• **Steven R. Singer,** DDS •

Abstract

Dental implants have become part of routine treatment plans in many dental offices because of their increasing popularity and acceptance by patients. Appropriate preplacement planning, in which imaging plays a pivotal role, helps to ensure a satisfactory outcome. The development of precise presurgical imaging techniques and surgical templates allows the dentist to place these implants with relative ease and predictability. This article gives an overview of current practices in implant imaging for the practising dentist, with emphasis on selection criteria. Imaging protocols for site assessment and restorative evaluation are discussed. This information will enable the dentist to select and use appropriate radiographic images (digital or film) for implant treatment planning, restoration and postoperative follow-up. Modalities presented include intraoral and panoramic projections, linear and complex motion tomography and computed tomography (CT). The use of CT image reformatting software such as Dentascan and SimPlant with 3-dimensional reconstructions is discussed.

MeSH Key Words: *dental implantation, endosseous; patient care planning; radiography, dental/methods*

This article has been peer reviewed.

Dental implants are gaining immense popularity and wide acceptance because they not only replace lost teeth, but are also permanent restorations that do not interfere with oral function or speech or compromise the self-esteem of patients. It is important to be able to place the implants in the mandible and maxilla with a high degree of precision. No tool in dentistry plays a more vital role in diagnosis and treatment planning than radiography.

Before attempting to treat a patient with a root-form dental implant, dentists must determine jaw size, boundaries and orientation of the vertical long axis of the jaw. In addition, internal anatomy should be visualized in 3-dimensional perspectives, including the proximity of nasal fossae, neurovascular bundles, pneumatization of the maxillae, soft tissue morphology and bone quality. Imaging information will allow optimum placement of the implants and enhance the success, both short and long term, of all subsequent stages of the procedure.

This article focuses on various types of imaging procedures, carried out before and during dental implant placement, and the diagnostic role of each modality. Various types of tomography and the use of current CT software for image reformation are discussed.

The Role of Imaging in Site Assessment and Treatment Planning

Before the advent of root-form implants, 3 basic types of implants were available: subperiosteal, blade and transosseous.[1] Dentists should be familiar with the radiographic appearance of the various implant fixtures and knowledgeable about current implant imaging techniques.[2,3]

Subperiosteal implants are metallic meshes that are custom built to fit over the alveolar process and under the periosteum.[3] Several metallic posts extend from the mesh into the oral cavity (above the mucoperiosteum) to support the prosthesis (**Fig. 1**). Blade implants are rectangular, similar to a razor blade. From the long side of the rectangle, one or more posts extend into the oral cavity to permit fixation of the prosthesis. Transosseous implants are still being used for highly resorbed mandibles; they are placed in the anterior region between the 2 mental foraminae.

Root-form implants are by far the most commonly used implants in dentistry today.[3] Osseointegrated root-form implants are made up of a fixture and an abutment. The fixture is the portion of the implant that is surgically embedded in the osseous tissue of the jaw. It is made of titanium, a material that promotes osseointegration. Fixtures are manufactured with or without threads[4,5] and some are

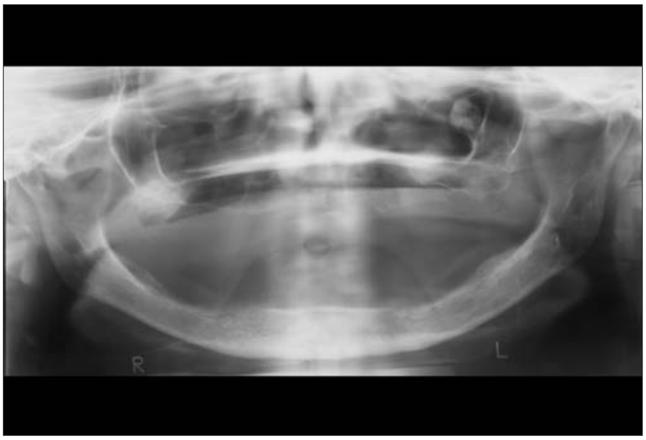

Figure 1: *Normal panoramic radiograph demonstrating relationships between structures in the mandible and maxilla. Note the presence of an osteoma in the left maxillary sinus in this otherwise asymptomatic patient.*

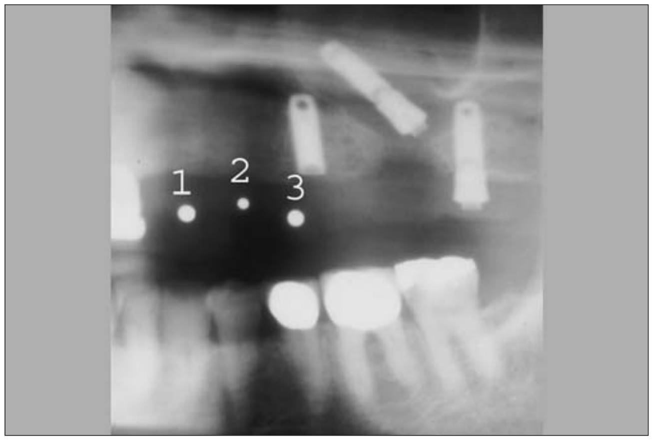

Figure 2: *Cropped panoramic radiograph showing ball bearings embedded in an acrylic template.*

coated with hydroxyapatite.[1–3] They come in various sizes, typically ranging from 3.25 to 3.75 mm in diameter and 7 to 10 mm in length.[6] The size of the implant depends on the amount of available bone. Dentists prefer the largest possible implant as it increases the surface area and provides stronger anchorage. It is always preferable to have 1–1.5 mm of bone on either side of the implant fixture and 1–2 mm of bone between the implant and the adjacent vital structures (mandibular canal, maxillary sinus, nasal fossa).[6] The abutment, which increases the height of the fixture to a level above the gingival surface, is attached to the fixture with an abutment screw. The top of the abutment screw contains a small hole that allows the dental prosthesis to be attached by a screw that runs through the prosthesis and into the abutment screw.[6] It is essential that the abutment be in intimate contact with the implant fixture. The screw is designed to be the weakest portion of the implant, so that in the event of unforeseen stress, it will separate, sparing the fixture.[6]

These fixtures and abutments can be previewed and their placement simulated on interactive tomograms. Today, the entire treatment planning can be completed virtually using interactive software such as SimPlant (Columbia Scientific Inc, Glen Burnie, Md.).[3]

Radiographs are deemed adequate if they satisfactorily reveal all pathoses in the pre-implant site and depict the quantity and quality of bone and proximity of neurovascular bundles, foraminae or air spaces. In other words, the bone should be visualized in all possible dimensions so that accurate data can be gathered and jaw anatomy can be visualized before implant placement. Naturally, the implant should be away from neurovascular bundles and anatomic sinuses to avoid perforations and the resultant complications.

Intraoral periapical views of the area of interest and panoramic views are recommended to begin with.[7] Intraoral periapical views offer the best resolution (line pairs/mm) among all the imaging modalities. Image quality is related to several factors, including the use of nonscreen films, short object–film distance, long source–film distance, tight collimation and controlled alignment of the film, object and imaging source.[4] Using these images, the target area can be carefully examined for trabecular patterns, residual roots, periodontium, as well as angulation of adjacent teeth. However, because periapical radiographs show a 2-dimensional perspective of 3-dimensional anatomy, they are not adequate to estimate the amount of available bone in the edentulous site. Also, their limited size makes them inadequate for evaluating large edentulous areas and associated maxillary and mandibular structures.

A good panoramic radiograph will outline the bony anatomy clearly and is generally used for diagnosis of gross pathoses within the jaws as well as the relation of anatomic structures such as sinuses, canals, fossae and foraminae to the implant site[8] (**Fig. 2**). Although some panoramic machines (Panelipse, Gendex, Des Plaines, Ill.) have uniform magnification (19%), in general, most machines have varied and unreliable magnifications (25% to 30%) especially in the vertical dimension. Magnification is more pronounced in posterior than in anterior areas.[8] This may give a false sense that more bone exists between the crest of the alveolar process and the inferior alveolar canal, nasal fossae or maxillary sinuses. Improper patient positioning may further contribute to image distortion.

Even properly positioned and exposed panoramic radiographs cannot be used for direct bony measurements unless the magnification factor for the target area is predetermined. Predetermination of the magnification factor can be accomplished by using a radiographic stent with ball

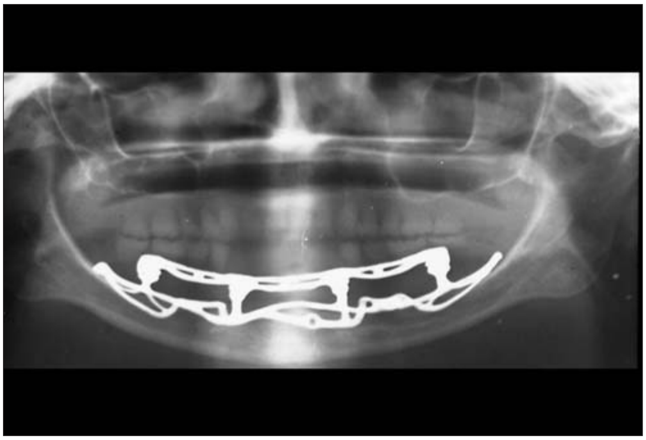

Figure 3: Panoramic radiograph demonstrating a mandibular subperiosteal implant.

bearings embedded in acrylic and imaged in the patient's mouth[3] (**Fig. 3**). The diameter of the ball bearings in the area can be measured radiographically and compared with their actual diameter. Bone measurements can then be adjusted accordingly. Measurements from panoramic projections are generally not precise enough for implant placement.[6]

Additional views are needed for the direct measurement of the prospective implant site.[9] The images commonly sought are:

- cross-sectional tomograms using linear or complex motion tomography or
- reformatted CT images using software such as Dentascan or SimPlant.

Cross-sectional tomography is adequate where replacement of a single tooth or several teeth within a limited area is expected and no significant anatomic variations exist.[4] Reformatted CT images are indicated if the patient is being evaluated for total jaw reconstruction or for multiple implants (i.e., more than 7) within the mandible or maxilla.[7] They are also recommended if ridge augmentation is required, if the sinuses may be breached during the procedure or if there are variations in the anatomy, atrophic changes or pathology. The thickness of the image layer must be adequate to achieve proper coverage; generally, a 1- to 2-mm layer is indicated. CT imaging requirements should be discussed with an oral and maxillofacial radiologist.[7]

An important aspect of radiographic evaluation should be a qualitative description of the bone in the target area.[6] The most favourable osseointegration is thought to occur only in certain types of bone.[10] Although there is no single universally accepted system for classifying bone quality in the maxilla and mandible, the Misch system[10] based on the radiographic appearance of bone has been widely used by clinicians. The Misch system divides bone into 4 subdivisions (D-1 to D-4) based on the observed bone density.

Figure 4: Linear tomogram of edentulous maxillary anterior region.

D-1 and D-2 bones generally have dense cortical plates with coarse trabeculae and small bone marrow spaces, D-1 (atrophic anterior mandible) being denser than D-2 (anterior maxilla, anterior and posterior mandible). D-3 (anterior and posterior maxilla) and D-4 (posterior maxilla) bones range from poorly mineralized or thin trabeculae to complete paucity of mineralized trabeculae (D-3 being denser than D-4).[10]

Imaging Modalities

The American Academy of Oral and Maxillofacial Radiology (AAOMR)[7] has described the selection criteria for dental implant imaging. To assess the suitability of an implant site, the clinician must be able to visualize the mesial–distal view of the region of the arch where implant placement is being considered. In general, the appropriate image for this purpose is a panoramic radiograph. Periapical views may be added in cases where more detailed images are required. If the panoramic radiograph shows that there is sufficient bone for implant placement in that dimension, the practitioner should then identify the potential implant sites and obtain cross-sectional images to evaluate the adequacy of bone in the buccolingual dimension. Panoramic radiographs are generally useful to rule out gross pathoses within the jaws.[7,8] Cross-sectional information can be acquired with either conventional tomography or CT,[9] with images recorded on film or digitally acquired. The choice of imaging technique is based on radiation dose, cost and availability of an oral and maxillofacial radiologist to interpret the images.

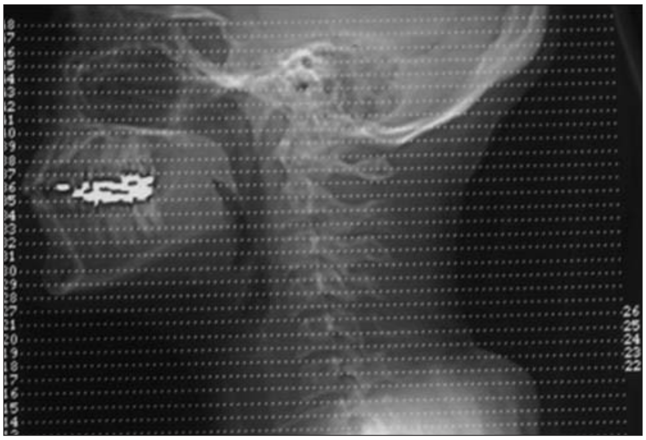

Figure 5: *Sagittal computed tomography (CT) scout image demonstrating the positions of the preselected axial slices.*

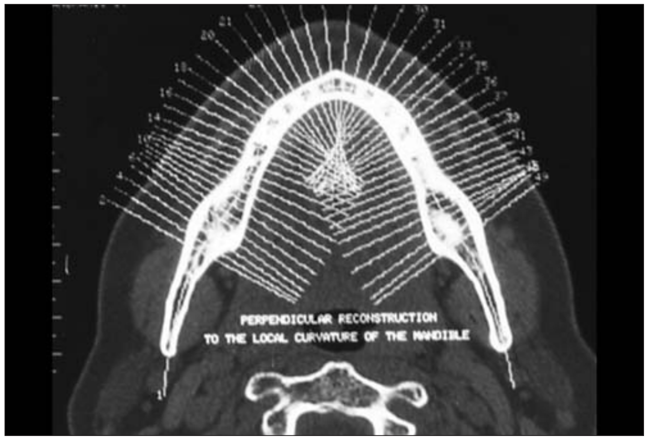

Figure 6: *Axial CT view of the mandible showing the potential cross-sectional slices that can be reformatted by Dentascan.*

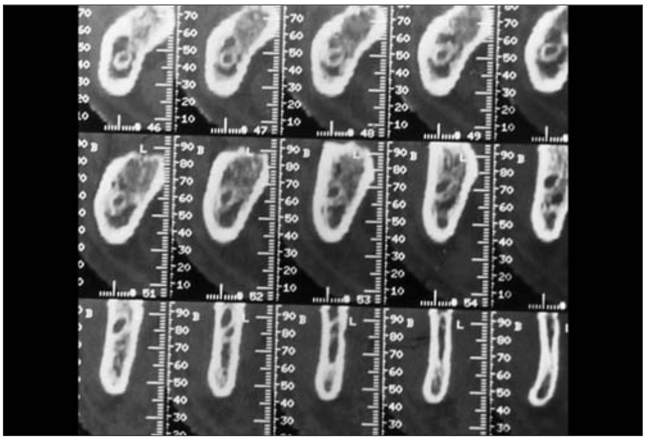

Figure 7: *Cross-sectional CT reformatted images of the patient in Fig. 6. Note how the mandible changes in width and shape in the more posterior slices, and the distinct appearance of the mandibular canal.*

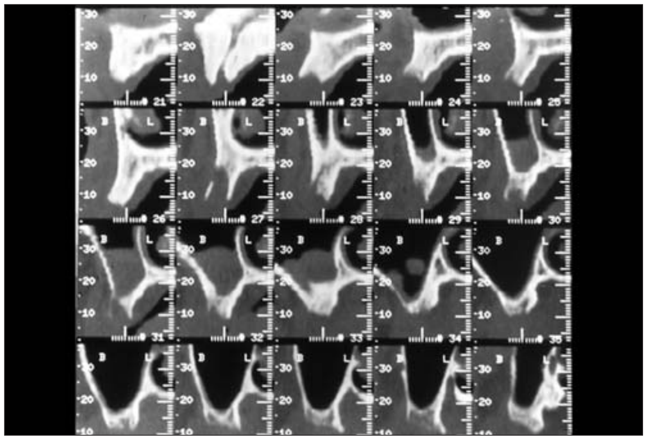

Figure 8: *Cross-sectional CT reformatted images of the maxilla showing the changes in the bony anatomy from anterior to posterior region.*

Tomography

In tomography, the x-ray source and image receptor are moved simultaneously in a controlled way that results in blurring of structures outside the desired image layer.[11] Various types of tomographic imaging are available.

Conventional tomography: In conventional tomography, different types of motion of the x-ray tube and the film are employed: linear (the simplest), circular, trispiral, elliptical and hypocycloidal. The images generated by complex motion tomography are generally sharper than those generated by linear tomography.[10]

Linear tomography: In linear tomography, the thickness of the image layer depends on the angle of rotation of the x-ray tube. When the path of the x-ray tube is short, i.e., the angle is small, the image layer is relatively thick. As the path of movement is increased, the image layer decreases. Based on this principle, there are 2 types of tomography: wide-angle tomography and narrow-angle tomography.[11] The main disadvantage of linear tomograms (Fig. 4) is the blurring of objects outside the focal plane, which produces "streak artifacts." These artifacts can be avoided by using complex motion tomography.[11,12]

Complex motion tomography: In most complex motion tomographic machines, tube and cassette motion is controlled by a computer, and is also called computer-assisted tomography. Computer-assisted tomography has become popular in implant and temporomandibular joint imaging with the advent of precise positioning techniques controlled by computer work stations.[3] CommCat (Imaging Sciences International, Hatfield, Penn.) is one such machine, which incorporates most of the complex motions of tomography (circular, trispiral, elliptical and hypocycloidal). A typical dental implant protocol is as follows.

The patient is positioned in the machine and an initial "scout film" is obtained and used to select appropriate

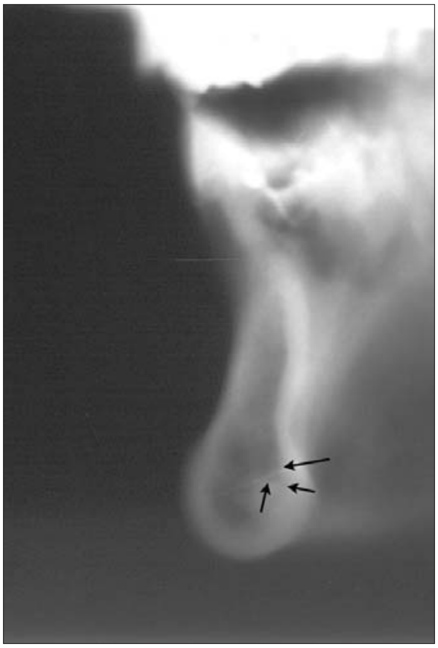

Figure 9: *Complex motion cross-sectional tomogram of mandible demonstrating the cortical niche sign (arrows).*

sections based on the shape and size of the arch. A prefabricated plastic stent with radiopaque markers can be used as a template to enable selection of the necessary cross-sectional images. Images can be obtained on film or digitally captured.

CT Imaging

Before the development of CT dental reformatting programs, information was obtained from panoramic, intraoral and cephalometric views alone.[9] Although these views are useful, they cannot be used to determine the buccolingual width of the mandible and maxilla,[13,14] and the clinician had to rely primarily on clinical assessment to determine whether the alveolar process was thick enough to accommodate an implant. Unfortunately, it was common to find during surgery that there was insufficient bone for implants. Conventional films could also not provide an indication of the proximity of neurovascular bundles in the buccolingual dimension with any reliability. Radiologists and dentists began to evaluate the efficacy of CT to assess these patients.[9,13] Axial and coronal CT images were only marginally helpful because of streak artifacts caused by metallic dental restorations and amalgam. However, reformatted images using thin-slice axial CT were found to be extremely useful because streak artifacts could be avoided. The anatomy of the arches could be displayed in multiple planes and the width of the alveolar process and basal bone could be accurately assessed. Reformatting software programs that display multiple panoramic and cross-sectional images soon became available.[9,14,15] One such program is Dentascan (GE Medical Systems, Global Center, Milwaukee, Wis.), and an advanced version, Dentascan Plus, is also now available.

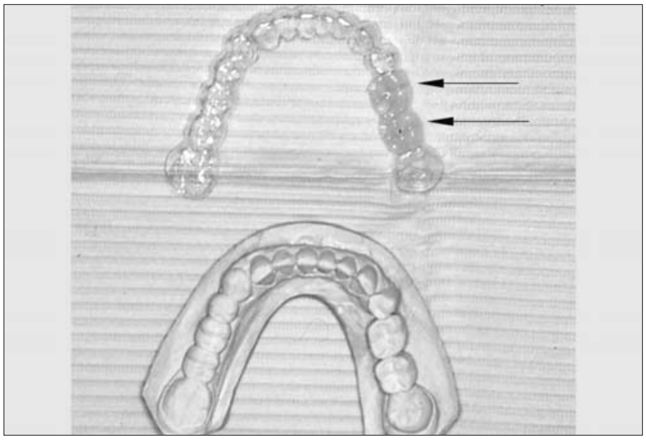

Figure 10: *Acrylic template along with the plaster model. Arrows indicate the radiopaque markers of the proposed implant area.*

Although CT reformatting programs may vary from manufacturer to manufacturer, the following guidelines generally apply. A scout image (**Fig. 5**) is obtained first, followed by axial images (**Fig. 6**). The scout image is used to determine the region of interest and machine settings. A computer-generated curved arc is superimposed on the axial views. Multiple numbered lines define the reformatted cross-sectional images that the program automatically deposits perpendicular to this curved arc (**Figs. 7** and **8**). The distance between the cross-sectional images can be varied; in general, a spacing of 1–2 mm is used. The mandibular canals and mental foraminae are easily visualized in cross-sectional images and the buccolingual width and contour of the jaw can be readily assessed.

Streak artifacts, which interfere with visualization of bone on direct axial images, do not degrade the reformatted cross-sectional images because the artifacts are not projected at the level of the alveolar process.[15]

When the program is completed, 3 types of images are generated: axial, cross-sectional and panoramic. The images can be printed on film using a specialized laser printer. A millimetre scale, displayed on the films, is used to verify the degree of magnification and to obtain accurate measurements with calipers. The oral and maxillofacial radiologist usually provides a complete and comprehensive report to the referring dentist, commenting on the bone density, general health of the mandible and maxilla, status of the dentition and measurements pertaining to the alveolar process. Anatomic structures like the maxillary sinus proximity, mandibular canal and mental foramen are identified for interpretation and reference. Three-dimensional reconstruction images are available with most Dentascan protocols.[9] They are of limited direct use in implant

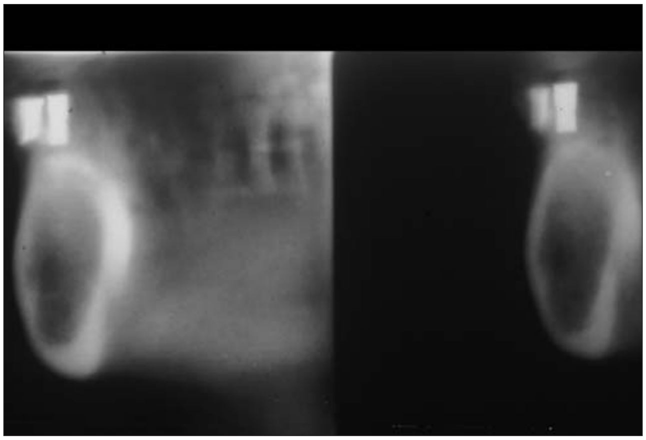

Figure 11: Cross-sectional complex motion tomographic slices of mandible. Note the relation of radiopaque markers embedded in the radiographic stent to the alveolar crest.

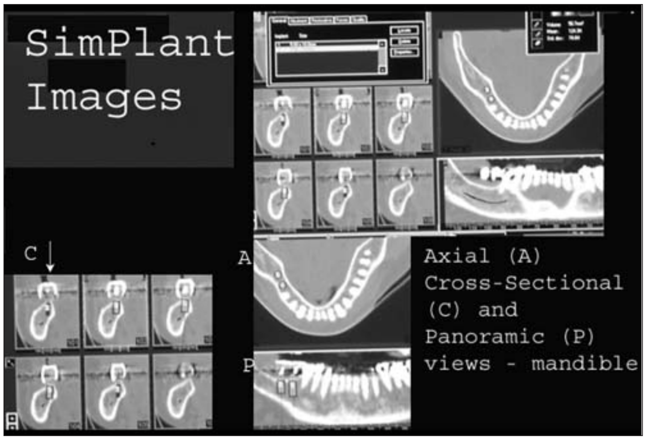

Figure 12: Reformatted and enhanced images produced using SimPlant software.

planning, but are helpful in allowing the dentist to envision the site, and because they are generated from the initial scan, they do not increase the radiation dose to the patient.[15]

It is extremely important to identify the mandibular canal on cross-sectional images and to measure the distance from the top of the alveolar ridge to the top of the canal. Normally, the canal can be readily seen on cross-sectional images of the posterior mandible. If the canal is hard to visualize on the cross-sectional images, 2 methods are commonly used to locate it. The first is known as the cortical niche sign,[9] which refers to an indentation along the inner medullary margin on the lingual cortex of the mandible. The cortical niche sign can also be seen in cross-sectional complex motion tomograms (**Fig. 9**). The mandibular nerve creates this niche as it traverses the mandible. It may not be present in all cases, but when present, it is an important clue to the location of the canal. This niche must be seen as a continuous defect on multiple cross-sectional images before it can be verified. The second method, "triangulation,"[9] utilizes the scale marker on the films to relate an anatomic structure seen on one view with its location on another view.

Radiographic templates are manufactured by the dentist after an impression of the ridge and teeth is obtained and in consultation with the implant surgeon.[16] A template is a clear acrylic device that fits snugly over the residual teeth and alveolar process (**Fig. 10**). Radiopaque markers are attached to the template to facilitate transfer of information from the radiographic images to the patient, such as localization of anatomic structures. In this fashion, the position of the implant fixtures and teeth in the restoration can be previewed (**Fig. 11**).

Templates serve a variety of purposes. They are used to select the appropriate site, decrease the degree of distortion and determine precise measurements. Radiographic templates can also be transferred to the surgical suite and used for accurate determination of the location and angle of placement of the implant.[2,3,9,13–15] This is extremely important for avoiding cortical perforations when implant sites are thin buccolingually.[17] In addition, the vertical angulation of the implant can be determined before placement so that the implant can parallel the long axis of adjacent teeth or other implants. This can simplify the restorative phase, when the path of insertion of the prosthesis is critical.

Introduced in 1993, SimPlant software (**Fig. 12**) combines CT imaging with computer-aided design. Before introduction of this software, implant treatment planning was usually performed using hard copy films or prints of reformatted CT images[17] with transparent overlays representing the implants. SimPlant uses raw data from the CT scan itself along with computer graphics to provide an impressive preoperative planning tool for placement of implants. The program permits the planner to vary the display of the reformatted CT images and to inspect the bony anatomy of the alveolar ridge.[17] Bone height and width can be easily measured from point to point. With this data in hand, it is possible to select the proper length and diameter of the implants as well as appropriate abutments. The angulation of the proposed implant can be modified on screen for optimal orientation with respect to natural teeth, other implants and anatomic structures. The software also has a feature that allows clear visualization of the inferior alveolar canal as well as other features for convenient viewing of simulated placement of implants.

Radiation Doses from Various Imaging Modalities Used in Implant Dentistry

With all imaging modalities, appropriate selection criteria must be applied.[7] The prescriber must consider potential

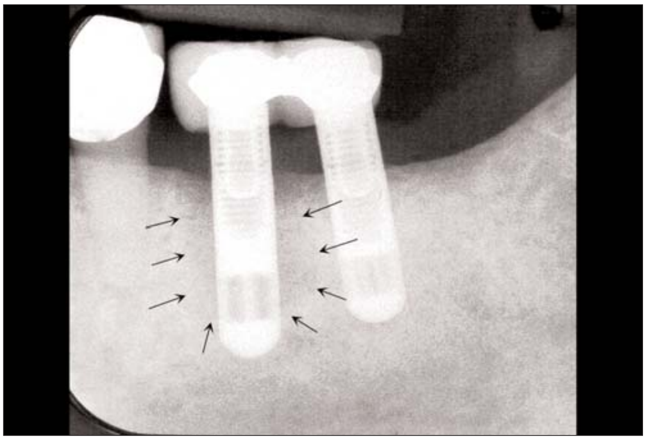

Figure 13: *Failing implant restoration. Arrows show saucerized area of bone loss.*

risks versus perceived benefits of the imaging procedure.[18] When the dentist prescribes a radiographic examination, the ALARA principle (as low as reasonably achievable) should be kept in mind. Radiographs should only be prescribed when the information cannot be obtained in any less invasive manner.

CT delivers a relatively large dose of ionizing radiation.[19,20] It is important to maximize the diagnostic yield while simultaneously limiting the field of view to the region of interest. Because the number and thickness of slices influence the total dose to the patient in a CT examination, the examination should be limited to the arch where the implants are anticipated. Frederiksen[18] and Frederiksen and others[19] estimated that an effective dose of 10 µSv is attained from a single periapical film exposure; 26 µSv from a panoramic projection; 150 µSv from a full-mouth survey; 761 µSv from the CT of the mandible; and 104 µSv from the CT of the maxilla. Frederiksen[18] estimated the effective dose per slice when using the Scanora linear tomography system (Orion, Helsinki, Finland) to be in the range of 1–30 µSv.

Magnetic resonance imaging (MRI) is not commonly used for implant imaging because bony detail cannot be readily appreciated.[13–15] There are no known contraindications to MRI for patients with existing dental implants.[21] From the standpoint of MRI safety, dental implants are to be considered similar to other internal orthopedic hardware (screws, plates, rods, artificial joints or penile prostheses).[22]

Imaging Protocols for Restoration and Postoperative Follow-up

Although routine use of radiographs to assess the status of implant fixtures is not necessary, when the clinical evidence indicates the need, periapical and panoramic radiographs may be used to evaluate the implants postoperatively.

Before the restorative phase, the implant is checked clinically for indications of successful osseointegration. Periapical projections are indicated to view the bone–implant interface. It is essential to view the entire implant fixture during postoperative assessment. Periapical views should be exposed using the long cone paralleling technique to ensure accurate dimensional representation of the implant and surrounding structures.

If clinical symptoms indicate, the bone–implant interface is examined radiographically for signs of failure such as a radiolucent rim around the implant body and loss of crestal bone (saucerization) at the implant site (**Fig. 13**). The greatest amount of peri-implant vertical bone loss occurs within the first year after placement of the implants, followed by a dramatic decrease in the rate of bone loss in subsequent intervals.[23]

In some instances, there is complete rejection of the implant fixture due to severe bone loss. Peri-implantitis is a term used to describe the lack of osseointegration along the implant–bone interface due to infection around the fixture.[21] Implantitis can be seen on periapical radiographs.

Current Trends and Future Perspectives in Implant Imaging

CT images have made possible the use of computer-milled surgical templates for computer-guided surgery.[24] Computer-milled surgical templates (Compu-Guide Surgical Template System, Implant Logic Systems, Cedarhurst, NY) are constructed using raw data from the CT scan and a simulated position blueprint obtained via a software program, such as SimPlant. Once the dentist develops the treatment plan, the coordinates of the simulated implant position are transferred to a 5-axis computer-controlled milling machine, which creates the appliance to the SimPlant specifications. A drill guide system is subsequently installed into the milled surgical template to direct the drilling of the osteotomes for implant placement.[18]

Conclusion

The excellent imaging modalities that exist today can enhance the success of and satisfaction with implant placement. Selection of projections should be made with consideration to the type and number of implants, location and surrounding anatomy. As in the case of all imaging, appropriate selection criteria must be applied individually to each patient. ❖

Dr. Mupparapu *is associate professor, University of Medicine and Dentistry of New Jersey, New Jersey Dental School, Newark, NJ.*

Dr. Singer *is associate professor, University of Medicine and Dentistry of New Jersey, New Jersey Dental School, Newark, NJ.*

Correspondence to: *Dr. Muralidhar Mupparapu, UMDNJ-New Jersey Dental School, Department of Diagnostic Sciences, Room D-860, 110 Bergen St., PO Box 1709, Newark, NJ 07101-1709, USA. E-mail: mupparmu@umdnj.edu.*

The authors have no declared financial interests in any company manufacturing the types of products mentioned in this article.

References

1. Shetty V, Benson BW. Orofacial implants. In: White SC, Pharoah MJ, editors. Oral radiology: principles and interpretation. St. Louis: Mosby, Inc.; 2000. p. 622–35.

2. Smith RA. New developments and advances in dental implantology. *Curr Opin Dent* 1992; 2:42–54.

3. Mupparapu M, Beideman R. Imaging for maxillofacial reconstruction and implantology. In: Fonseca RJ, editor. Oral and maxillofacial surgery: reconstructive and implant surgery. Philadelphia: WB Saunders; 2000. p. 17–34.

4. Sahiwal IG, Woody RD, Benson BW, Guillen GE. Radiographic identification of threaded endosseous dental implants. *J Prosthet Dent* 2002; 87(5):563–77.

5. Sahiwal IG, Woody RD, Benson BW, Guillen GE. Radiographic identification of nonthreaded endosseous dental implants. *J Prosthet Dent* 2002; 87(5):552–62.

6. DelBalso AM, Greiner FG, Licata M. Role of diagnostic imaging in the evaluation of the dental implant patient. *Radiographics* 1994; 14(4):699–719.

7. White SC, Heslop EW, Hollender LG, Mosier, KM, Ruprecht A, Shrout MK. An official report of the American Academy of Oral and Maxillofacial Radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2001; 91(5):498–511.

8. Truhlar RS, Morris HR, Ochi S. A review of panoramic radiography and its potential use in implant dentistry. *Implant Dent* 1993; 2(2):122–30.

9. Wyatt CC, Pharoah MJ. Imaging techniques and image interpretation for dental implant treatment. *Int J Prosthodont* 1998; 11(5):442–52.

10. Misch CE. Density of bone: effect on treatment plans, surgical approach, healing and progressive bone loading. *Int J Oral Implant* 1990; 6(2):23–31.

11. Curry TS, Dowdey JE, Murry RC Jr. Christensen's physics of diagnostic radiology. 4th ed., Philadelphia: Lea & Febiger; 1990. p. 242–8.

12. Ekestubbe A, Grondahl K, Grondahl HG. The use of tomography for dental implant planning. *Dentomaxillofac Radiol* 1997; 26(4):206–13.

13. Miles DA, Van Dis ML. Implant radiology. *Dent Clin North Am* 1993; 37(4):645–8.

14. Frederiksen NL. Diagnostic imaging in dental implantology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1995; 80(5):540–54.

15. Abrahams JJ. Dental CT imaging: a look at the jaw. *Radiology* 2001; 219(2):334–45.

16. Small BW. Surgical templates for function and esthetics in dental implants. *Gen Dent* 2001; 49(1):30–2, 34.

17. Rosenfeld AL, Mecall RA. The use of interactive computed tomography to predict the esthetic and functional demands of implant-supported prostheses. *Compend Contin Educ Dent* 1996; 17(12):1125–8, 1130–2.

18. Frederiksen NL. X rays: what is the risk? *Tex Dent J* 1995; 112(2):68–72.

19. Frederiksen NL, Benson BW, Sokolowski TW. Effective dose and risk assessment from computed tomography of the maxillofacial complex. *Dentomaxillofac Radiol* 1995; 24(1):55–8.

20. Clark DE, Danforth RA, Barnes RW, Burtch ML. Radiation absorbed from dental implant radiography: a comparison of linear tomography, CT scan and panoramic and intra-oral techniques. *J Oral Implantol* 1990; 16(3):156–64.

21. Reisken AB. Implant imaging: status, controversies and new developments. *Dent Clin North Am* 1998; 42(1):47–56.

22. Sawyer-Glover AM, Shellock FG. Pre-MRI procedure screening: recommendations and safety considerations for biomedical implants and devices. *J Magn Reson Imaging* 2000; 12(1):92–106.

23. Manz MC. Factors associated with radiographic vertical bone loss around implants placed in a clinical study. *Ann Periodontol* 2000; 5(1):137–51.

24. Klein M, Abrams M. Computer-guided surgery utilizing a computer-milled surgical template. *Pract Proced Aesthet Dent* 2001; 13(2):165–9.