Published in final edited form as:

Dent Clin North Am. 2011 January ; 55(1): 141–158. doi:10.1016/j.cden.2010.08.001.

Cone Beam Computed Tomography for the Implant Patient

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Abstract

Cone beam CT scanning has brought a new dimension to dentistry for the implant patient. In all aspects of diagnosis, treatment planning, surgical preparation and execution, follow-up, and management of complications, we now can treat our patients with increased precision and predictability. However, as with all new technology, we must consider the added cost to the overall treatment and the risks vs. benefits to each individual patient.

Presurgical dental implant assessment is, in a way, a unique task. Apart from the various diagnostic questions that need to be answered with the proper radiographic image or technique (such as the presence of neighboring structures and anatomical limitations), dimensional accuracy is also of great importance. Traditional dental imaging modalities (intraoral and panoramic images) only partially address the diagnostic concerns associated with implant planning and their accuracy varies upon technique and operator. On the other hand, medical computed tomography, CT, although providing answers to diagnostic questions and demonstrating remarkable accuracy, is rarely in touch with dentistry. Moreover, the radiation exposure to the patient is significantly higher than traditional dental radiographs. This gap between the traditional dental imaging modalities and medical CT was bridged with the introduction of cone beam computed tomography, CBCT, for imaging the orofacial structures.

What Makes Cone Beam Computed Tomography Different Than Other Imaging Modalities Used in Implant Imaging?

The introduction of CBCT in dentistry is interlaced with a new paradigm in maxillofacial diagnosis known as “interactive diagnostic imaging.” This new paradigm has its foundations on the concept of “multiplanar imaging/reformatting,” which is not new in medical imaging. This allows for the reconstruction of a variety of images in any possible plane (axial, coronal, sagittal, and 3-dimensional viewing) by selective display of data out of a volume of acquired information. This property is linked directly to the fundamentals of CBCT data acquisition that is volumetric in nature. The CBCT scanner acquires information from a volume that, for the convenience of computations, is made up of numerous, small volume cubes, known as voxels (volume elements). A portion of this data can be displayed on a monitor by properly selecting some of the voxels based on region (planar imaging) or

density (volume and surface rendering). A panoramic-type image can be extracted by carefully selecting an uninterrupted curved sequence of voxels along the maxilla or the mandible. This will result in a panoramic reconstructed image that will be a reflection of the selected voxels by means of density and diagnostic information. Although multiplanar reconstruction is not a new concept in medical imaging, in most cases the reconstructed images were recorded on static media as film or paper prints without any potential for interactivity apart from the operator of the main workstation of the computed tomography scanner.¹ CBCT technology embraced interactive diagnosis soon after its introduction almost 10 years ago. This has contributed significantly in moving dental imaging from the static traditional images to the fingertips of the user, who now is responsible for the retrieval of the diagnostic information that may not be always obvious.

How Does CBCT Help With Implants?

Although CBCT has been used for both pre-operative and post-operative dental implant assessment, its contribution to the former is by far better documented in the literature. CBCT contributes in pre-implant evaluation in a variety of levels: The first and most important includes diagnostic considerations in regard with the proposed implant site.

Preimplant Evaluation: Diagnostic Considerations

CBCT provides answers as to how suitable an edentulous location is for implant placement. Based on the concept of multiplanar reformatting described earlier, the proprietary software available with all CBCT scanners can provide reconstructions directed towards implant planning. These may include multiple, sequential panoramic, cross-sectional, sagittal, and any other type of images of the proposed implant site(s). These images can be of variable size and thickness, and in most scanners, based on the preferences of the user (Figures 1 and 2). Their formation is a simple interaction between the user and the volumetric data in a certain location. Once the reformatted images are made, measurement tools can provide alveolar bone height and width estimates (Figure 3). Angular estimates are also available. Both will assist in selecting the proper fixture size and insertion path.

One may wonder about the accuracy of these measurements since dentists are relying on them in a variety of tasks. CBCT manufacturers incorporate advanced mathematical algorithms after image acquisition, so when the data are projected on screen they are already corrected for magnification. These measurements are very accurate for most of the CBCT scanners in the market.²⁻⁴

Dental implants are frequently placed in areas of the jaws in proximity to important anatomical structures that may need be preserved or respected during implant placement. The mandibular canals, mental foramina, submandibular gland fossae, lingual foramina, and neighboring teeth are some of these structures in the mandible. The maxillary sinuses, nasal cavity naso-palatine canal, and neighboring teeth are some of the maxillary anatomical structures that may pose limitations in implant placement. While some of these structures can be visualized with traditional dental images (panoramic, intraoral views), the spatial complexity of others (including the maxillary sinuses, nasal cavity and naso-palatine canal)

may limit the utility of these images. Such spatial concerns make the use of sectional imaging a necessity.⁵ Cross-sectional images make the identification of undercuts in the alveolar bone easy. Depending on their size, these undercuts may limit or compromise a site for future implant placement⁶ (Figure 4).

Some anatomical structures, including the mandibular canals, are simply depicted better with advanced imaging including CBCT. Moreover, the multi-planar reformatting view at different planes (axial, coronal, sagittal, cross-sectional) increases the chances that the mandibular canal be located even if it is lightly corticated.^{7,8} To further assist the clinician in implant planning in the vicinity of the mandibular canal, the path of the inferior alveolar nerve can be traced in the canal and evaluated in relation to the planned implant position (Figure 5).

Certain factors that contribute to alveolar bone quality can be assessed with CBCT scans. The thickness and integrity of the cortices of the alveolar bone, the continuity of the alveolar crest, the integrity of its boundaries with anatomical structures in the proximity and the architecture of the alveolar bone are all considered determinants of bone quality. The bone density is considered to be directly proportional to the load-bearing capacity of the bone and implant failure has been linked to low bone density.⁹ Thus, accurate estimation of the alveolar bone density in the implant site would be of great benefit. However, density estimates provided by the various CBCT systems demonstrate great variation and inconsistency (sometimes even within the same system). This is mainly due to the high level of noise in the acquired images and inhomogeneities in the detection system of CBCT scanners. In addition, the provided estimates are gray scale values (brightness values) and not true X-ray attenuation values, known as Hounsfield units, HU, such as provided by medical CT scanners. Lately, attempts have been made to link the grey level values provided by CBCT to HU.¹⁰

It is important to identify any pathological conditions in the region of a proposed implant site, including inflammatory processes, retained roots, or maxillary sinus inflammation.¹¹ The status of prior grafting procedures (sinus grafts, alveolar ridge grafts, etc) can also be assessed with CBCT scans (Figure 6). Previously after a sinus or alveolar ridge augmentation procedure, a panoramic radiograph would be taken to evaluate the graft incorporation and proximity of the graft to any vital structures. Now with the utilization of CBCTs, we can more accurately evaluate bone graft quality and quantity, which can also be combined with implant treatment planning as described below. Indeed, this is a significant improvement from the panoramic radiograph, where both techniques expose the patient to a similar amount of radiation. In addition, if a complication were to arise, the CBCT scan can be utilized to evaluate proximity of the bone graft or fixation screws to the inferior alveolar nerve or the consolidation of graft material below the maxillary sinus.

Preimplant Evaluation: Computer-assisted Planning

While a few manufacturers of CBCT scanners offer advanced implant planning software, the vast majority of computer-assisted planning applications are third-party applications. These programs use the acquired CBCT data exported to a universal format known as DICOM

(digital imaging and communications in medicine) format, which was introduced by ACR-NEMA (American College of Radiology-National Electrical Manufacturers Association). The development of this standard was the response to the growing need for standardization of the image format for export and transfer of medical images including CT scans, MRIs, and ultrasound. Compliance with this standard allows CBCT data exported in DICOM format to be imported, viewed and manipulated by a variety of third-party applications.

Some third-party applications provide considerably advanced dental implant planning with the introduction of implant placement simulations, 3-D visualization, marking of the mandibular canal and other anatomical structures of interest, advanced segmentation techniques, and more. With these applications, the DICOM data of the CBCT scan is imported and converted to a proprietary format that is not free of cost. Once the conversion is completed, a broad array of dental implant planning tools combined with realistic and undistorted views of the maxillofacial skeleton as well as the soft tissue are possible. These applications incorporate libraries of additional data that include manufacturer specific CAD/CAM (computer-aided design/computer-aided manufacturing) files of dental implants, abutments, prosthetic appliances, etc., which are quite realistic. These can be maneuvered and manipulated within the framework of the virtual world of 3-D imaging¹² (Figures 7 and 8).

Most of these software packages continually update their dental implant libraries so they can be readily available for the user during implant planning. In most cases, the specific implant planned is visualized in at least three views: cross-sectional, axial, and sagittal. A fourth view of the dental implant in a solid or transparent 3-D virtual model of the maxilla or the mandible can also be viewed. By these means, a dental implant is maneuvered in a 3-D space instead of two-dimensionally, with the goal of a high degree of precision in placement.

When several implants are planned, certain tools of the application can secure parallel orientation. If the dental implant is to be placed at an angle, the angle can be determined so the appropriate abutment can be selected.

Considerable information is revealed by removing the virtual bone leaving 3-D representations of the existing natural teeth. These views facilitate viewing the orientation of the planned dental implants in relation to the existing dentition. In addition, these views can help to prevent possible damage to natural teeth during implant placement.

When a radiographic guide with opaque teeth indicating the desired position and orientation for the final restorative work is used, the virtual implant placement will take into account the shape, size, and spatial orientation of the prosthesis and will allow for proper abutment selection prior to the actual surgical procedure. In this case, the radiographic guide can be removed or added on the 3-D and planar images to accommodate the simulated implant placement.¹³

It is often useful to be able to isolate, extract, or add certain structures or objects that are an integral part of the scanned volume (for example, the mandible, teeth, or surgical guides). To do so, these structures need to be circumscribed or selected, most frequently by means of

density or natural existing boundaries. This process is known as segmentation, which allows for different manipulation of selected data. The segmented data can later be added as a layer on the initial 3-D volume demonstrating their new attributes when needed. In this way, if the mandible is segmented, it can be removed from its articulation with the temporal bone to permit visualization of the glenoid fossa. Similarly, if segmented, certain teeth can be removed from the adjacent dentition, illustrated with a different color, or rendered transparent, to assist in assessing their relationship with neighboring structures. Segmentation is a labor-intensive and time-consuming process that requires an advanced level of knowledge of the application being used, as well as increased cost.

Preimplant Evaluation: Computer-assisted Design/Computer-assisted Manufacturing (CAD-CAM)

To take preimplant evaluation and surgical planning to the next step, CAD-CAM generated surgical guides can be fabricated. After the implant system, diameter, length, and angulation are determined and set, the data can be sent over the internet to a lab technician to fabricate a CAD-CAM surgical guide (Figure 9). This guide can be used during the surgery to replicate the computer-planned procedure, avoiding anatomic structures and allowing for more precise implant placement. Some of these proprietary software programs have even gone to the next step where provisional and final restorations are fabricated off the planned implant positions during treatment planning.¹⁴ Although this is only done in select cases, it demonstrates how new technologies can influence current surgical techniques and drives is to continue to improve clinical accuracy and reduce potential complications.

Postoperative Dental Implant Assessment

The factors that determine the success of an implantation procedure and the longevity of the dental implant are associated mainly with the appearance of the alveolar bone around the dental implant. The dental implant/bone interface, as well as the alveolar bone height in relation to the neck of the dental implant, is crucial to the success of the implant. A tight interface without any presence of a thin radiolucent line surrounding the dental implant and fairly distinct alveolar bone margins around the dental implant are signs of a well-osseointegrated dental implant. However, bone loss around existing dental implants does occur and literature has provided ample information and documentation about the rates at which evident bone loss is acceptable.^{15,16}

In general, periapical radiographs made under standardized conditions, can produce comparable images of the dental implants and the surrounding bone over time, and can provide a fairly accurate assessment of the alveolar bone crest and possible marginal bone loss mesially and distally to the implant and may be sufficient.¹⁷ However, the marginal bone on the buccal and lingual/palatal surface of the dental implant, the proximity of the implant to the respective plates (buccal, lingual/palatal) and possible perforation of the plates cannot be assessed with periapical views. If the postplacement problems are considerations, then postimaging may be required. Unfortunately, metallic and beam hardening artifacts, inherent in computed tomography, may obscure detailed evaluation of the dental implant bone interface or may result in ghost-like radiolucencies around dental implants (and other

high in density structures) that may imitate peri-implant bone loss and should be viewed with caution (Figure 10).

Conclusions

Dental implant diagnostics and treatment related applications are the biggest beneficiary of CBCT technology. This technology has revolutionized every aspect of the dental implant treatment from planning to surgery to the final restoration. However, despite many technological advances, CBCT is not free of limitations. It is the dental professional whose knowledge and integrity will make the difference for the benefit of the patient. Strict adherence to standards, guidelines, sound knowledge of the applications and limitations of this technology and proper precautions for the patient will contribute to extracting the most out of CBCT images.

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Figure 1.
Standard display format for the ICAT CBCT scanner including an axial image, reformatted panoramic, and a series of cross-sectional images, which can be scrolled throughout the maxilla or mandible.

Figure 2.
Display format for the scanner GALILEOS (SIRONA dental Systems) which includes sagittal images in addition to cross-sectional images.

Figure 3.
Kodak 9000: A slightly different display and choice of measurement tools.

Figure 4. Cross-sectional images in the anterior mandible as part of preimplant assessment. The marked lingual undercut has thinned the mandibular bone significantly. The anterior mandible is a region in which usually alveolar bone of adequate dimensions for implant placement exists, even if the rest of the mandible suffered extensive atrophy.

Figure 5. Panoramic view of CBCT scan. Outline of the inferior alveolar nerve in the mandibular canal showing proximity of planned implant site to the nerve.

Figure 6.

a. Homogenous, rounded, bilateral sinus grafts demonstrating minimal or no inflammatory response in the respective maxillary sinuses. This appearance is consistent with a successful graft. Alternatively, the graft in Figures B (coronal images), C (cross-sectional images) are irregular in shape and undermined by soft tissue. Fragments of the graft material appear to floating around the grafts. This appearance indicates failing sinus grafts, bilaterally. This may delay the implant placement significantly or postpone it indefinitely.

Figure 7.

The implant planning screen in one of the fairly widely used implant planning applications (Anatomage, In Vivo). Realistic implant images are maneuvered in space so as the most appropriate insertion path will be selected.

Figure 8.

The implant planning screen in one of the most widely used implant planning applications (Simplant, Materialize). The four windows show five implants placed in a simulated implant surgery in different views: cross-sectional (upper left), axial (upper right), panoramic (lower left), and 3-D (lower right). In this case, a radiopaque radiographic guide was used to simulate the missing teeth and to guide for proper implant placement based on the future restorative work. Since the guide was of a different density than the rest of the tissues and structures represented in the scan, it could be segmented. This provides the opportunity to have it removed or added based on need during treatment planning.

Figure 9.

A surgical guide applied on a maxillary biomodel. Both were manufactured using data exported from the case shown in Figure 8 with planned Simplant (Materialize). The metallic rings will accommodate the implant drills during implant surgery and will orient them into the exact location and depth planned earlier during the simulated placement. These guides could be either soft tissue- or bone-supported.

Figure 10.

A-C. The variable-width radiolucent zones surrounding the dental implants indicate peri-implant inflammatory lesions. Figure D. The linear radiolucent line present on the lingual aspect of the dental implant is a “beam hardening artifact” imitating a peri-implant

inflammatory lesion. Note the bone loss on the crestal third of the buccal cortex, on the same implant. Figure E. Severe metallic artifact prevents detailed assessment of the dental implant.