REVIEW

IMAGING MODALITIES IN IMPLANT DENTISTRY

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ABSTRACT

Rehabilitation of missing teeth with the use of dental implants has become the most accepted mode of treatment in modern dental practice. Success in oral implantology is highly dependent on proper diagnosis and pre-operative treatment planning, a gap that has been filled by currently available diagnostic imaging modalities. This article reviews various common imaging modalities used in implant dentistry along with an analysis of their clinical application.

INTRODUCTION:

Successful rehabilitation with implants is highly dependent on proper diagnosis and treatment planning; this is dependent on accurate imaging as well as skillful interpretation. Until the late 1980s, conventional radiographic techniques such as intraoral radiographs, cephalometric and panoramic views were the accepted standards. Evolving from there, many developments in cross-sectional imaging techniques, such as spiral tomography and reformatted computerized tomograms, became increasingly popular in the preoperative assessment and planning of patients needing implants 1.

In the year 2000, The American Academy of Oral and Maxillofacial Radiology recommended that clinicians should employ cross-sectional imaging to plan implant cases 2. The Academy also specified that conventional cross-sectional tomography should be the preferred method of imaging for most implant patients 3.

The variety of imaging modalities available vary from simple 2-Dimensional views such as panoramic radiographs to more complex views which allow image visualization in multiple planes 1. These imaging techniques should ideally enable the operating dentist to assess the quality and quantity of bone present in addition to visualizing the locations and proximity of critical internal anatomical structures to the implant site 1.

This article discusses the various imaging modalities that can be used in implant dentistry and discusses their indications, advantages and disadvantages.

REQUIREMENTS OF AN IMAGING MODALITY:

Any diagnostic imaging modality should ideally satisfy the following basic principles:

- Adequate number and types of images should be obtainable in order to provide required anatomical information.
- The imaging technique selected should provide the accurate required information.
- It should be possible to accurately relate the images available to the anatomy of the patient.
- The images obtained should be with minimal distortion.
- If more than one imaging modality is feasible, the imaging information should be governed by the ALARA (As Low As Reasonably Achieved) principle 3.
- It should be affordable for most patients.
IMAGING MODALITIES AVAILABLE:

Prior to the placement of dental implants the operating dentist needs to have a fairly good idea of the quality and quantity of bone available for implant placement, the precise location of the mandibular canal to avoid injury of any sorts to the neurovascular bundle, and location of the floor of the maxillary sinus to prevent sinus wall perforations thus minimizing chances of inadvertent oro-antral communications and consequent infections.

Imaging modalities for dental implants can be broadly classified as Analog or Digital and 2-Dimensional or 3-Dimensional imaging modalities. Analog imaging modalities include peri-apical radiographs, occlusal radiographs, panoramic radiographs and 2-Dimensional lateral cephalometric radiographs which use X-ray films and / or intensifying screens as the image receptors. Images obtained by the use of digital imaging modalities provide better information with regard to depth, width, height and image clarity. These modalities include computed tomography, tuned aperture computed tomography, cone-beam CT and magnetic resonance imaging.

Intra oral peri-apical and occlusal radiographs:

Both intraoral peri-apical and occlusal radiographs provide images with good reproduction of details. Peri-apical radiographs produce high resolution planar images. They may be used during the initial stages of clinical examination to evaluate small edentulous spaces, status of teeth adjacent to the planned implant site and/or regions of single implants during surgery to determine implant alignment and placement. They may also be used post-surgery to check for the presence of any pathosis and/or prognosis during recall appointments. Vertical height, architecture and bone quality, bone density, amount of cortical bone and amount of trabecular bone can also be determined to some extent with the use of peri-apical radiographs. Some of the primary advantages of these radiographs are ease of availability, affordable cost and low radiation dose exposure to the patients.

However no information on the width of the available bone and the proximity of critical anatomical structures is possible with the use of peri-apical radiographs. Studies have shown that only 53% of measurements from alveolar canal to superior wall of mandibular canal were accurate within 1mm. In comparison, almost 94% of all measurements made from CT images were accurate within 1mm.

When peri-apical radiographs (Figure 1) are used it is mandatory that exposure should be made using the paralleling angle technique. This helps limit both distortion and magnification which is a commonly encountered problem.

Occlusal radiographs are planar radiographs. An occlusal radiograph is placed between the occlusal surfaces of the teeth with the central beam directed at 90° to the plane of the film. The patients head is rotated so that the film is at right angles to the floor. The main application of occlusal radiographs is to determine the bucco-lingual dimensions of the mandibular alveolar ridge. However, due to anatomic constraints its application in the maxilla is limited.

The main disadvantage of occlusal radiography is that it records only the widest portion of the mandible and little information is available regarding the width of the crest which is actually of chief interest to the operator. Hence, its use in implant dentistry is limited.

Digital peri-apical imaging:

Digital radiographs are captured electronically, loaded into, viewed and stored in a digital format. These image receptors allow for instantaneous image acquisition with image quality either equal to or better than that of dental films. The images obtained can be viewed in the dental operatory on a video monitor. With the aid of the various digital tools present in the software, the clinician can magnify, reduce, color, lighten, darken and record measurements required for implant placement.

Besides being versatile in its interpretation, digital radiography also eliminates the space, equipment, time required for processing a conventional IOPA (Intra-oral peri-apical) radiograph and reduces radiation exposure by almost up to 90%.

The digital imaging modalities can be classified as indirect and direct. Indirect digital imaging makes use of a small photosensitive imaging plate coated with phosphorus. Once exposed, this plate is loaded into a scanner which reads the image and converts it to digital form.

In direct digital radiography, the x-ray is taken on a sensor and the image is directly loaded in to the computer.

Panoramic Radiographs:

Panoramic radiographs produce a single image of size 5”x11” of the maxilla, mandible and its supporting structures in a frontal plane (Figure 2). It provides for better visualization of the jaws and anatomical structures. This modality of imaging has highly variable magnification in the horizontal plane when compared to the vertical plane.
The main disadvantage of panoramic radiography is that the procedure cannot be performed in the dental operatory and requires additional set up. Also, panoramic radiography has lesser resolution than peri-apical or digital peri-apical radiography and hence suffers from magnification and distortion.

The advantages of this form of radiography includes ease of identifying opposing landmarks, ability to measure vertical height of bone in the area of interest, is not time consuming to capture, is convenient and easy to use.

Zonography:

This is a variation of the panoramic X-ray machine. The images obtained are cross-sectional images of the jaws. The tomographic layer obtained is relatively thick. This technique allows the operator to visualize the relationship of critical structures to the implant site in different planes. However a major disadvantage of Zonography is that there is superimposition of the adjacent structures over the obtained image giving a blurred appearance and hence limiting its usage as a diagnostic tool. Also, this technique cannot determine different bone densities and diseases at the site of implant placement.

Cephalometric radiography:

Cephalometric radiography can be obtained in Lateral and oblique projections. These provide a one-to-one image of the relationship between the maxilla, mandible and skull base in the mid-sagittal plane. The projections obtained usually show a 10% magnification with a 60 inch focal object and a 6 inch object-to-film distance.

The images obtained help in determining the feasibility of implant reconstruction of the edentulous alveolus in its present position or in establishing the need for orthognathic correction as part of the Various studies have shown that superimposition of oblique cephalometric radiographs may be used to determine tooth movement in implant cases.

Tomography:

Tomography is a generic term formed by the Greek words, Tomo (Slice) and Graph (Picture). This technique enables visualization of a section of the patients’ anatomy by blurring regions above and below the region of interest. Various image slices are obtained by either adjusting the position of the fulcrum or position of the patient relative to the fulcrum.

The slices obtained are 1mm thick and suitable for both pre- and post-implant placement assessment. The images are produced at a constant magnification and therefore measurements may be made directly by using a special ruler with the appropriate scale or in the case of digital images by using a measurement program after calibration.

This modality is technique sensitive as it causes significant blurring of the images due to superimposition of the structures outside the plane of focus. The degree of blurring usually depends on the distance of the other planes from the projected plane. Hence this technique is not suitable in case of multiple implant sites.

Various methods like hypocycloidal or spiral and linear pattern movements have been employed to reduce the blurring artifacts and produce sharper images.

Conventional Tomography:

Linear tomography is the simplest form of tomography where the X-ray tube and film move in a straight line. This is a one dimensional motion which produces blurring of adjacent sections in one dimension resulting in linear streak artifacts also referred to as ‘parasite lines’ in the obtained image, making it obscure. The magnification factor is constant in all directions but varies with different manufacturers. Conventional tomography (Figure 3) is ideal when planning for single implant sites or for those within a single quadrant.
critical structures to the implant site. Reconstructive plan by displaying a soft tissue profile to evaluate profile alterations after prosthodontic rehabilitation\(^9\). Oblique lateral cephalometric radiographs give reproducible height measurements in the mandible, but the information is two dimensional and hence care must be taken to avoid positioning errors due to the beam angulations\(^7\).

The lateral cephalometric radiograph (Figure 4) is the imaging modality of choice in completely edentulous patients for measuring the horizontal dimension of the alveolar process\(^8\). The main disadvantage of this technique is no information on bone quality can be obtained. It gives more accurate information on inclination, height and width of the alveolar bone at the midline\(^7\).

However, not much information can be obtained on bone quality\(^7\).

![Lateral cephalometric radiograph](image)

**Figure 4: Lateral cephalometric radiograph**

**Computed Tomography:**

Computed tomography was invented in 1972 by British engineer Godfrey Hounsfield of EMI Laboratories, England and by South Africa-born physicist Allan Cormack of Tufts University, Massachusetts. The first CT scanners were introduced in the field of medicine during the mid-1970s and they soon replaced complex tomography by the early 1980s. Computed tomography was originally developed for the depiction of soft tissues, particularly the brain, and not for high-contrast skeletal structures.

A CT scanner consists of radiographic tube that emits a finely collimated, fan-shaped x-ray beam directed to a series of scintillation detectors or ionizing chambers. Depending on the scanner’s mechanical geometry, both the radiographic tube and detectors rotate around the patient. The CT image is a digital image made up of matrix of individual blocks called voxels, which has a value referred in Hounsfield units that describes the density of the image at that point. Each voxel consists of 12 bits of data and ranges from -1000 (air) to +3000 (enamel/dental materials) Hounsfield units. CT scanners are standardized at Hounsfield value of 0 for water. CT image is reconstructed by computer, which mathematically manipulates the transmission data obtained from multiple projections. Thin sections of the structures of interest can be made in several planes and viewed under different conditions\(^4\).

CT has several advantages over conventional film 1) Differences between tissues that differ in physical density by less than 1% can be distinguished without super-imposition 2) Multiplanar views of data allowing rapid correlation of the different views. 3) CT can produce 3 dimensional images with high resolution with uniform magnification 4) Three-dimensional reconstruction is possible 5) CT is useful for the diagnosis of disease in the maxillofacial complex, including salivary glands and TMJ 6) As compared to peri-apical and panoramic radiography Computed tomography provides better information regarding position of the mandibular canal.

There are inevitably some disadvantages to the application of CT imaging modalities 1) high absorbed dose of radiation to the patient in comparison with the dose administered through panaromic and linear tomography (3). 2) limited availability of reconstructive software 3) expense\(^13\).

**Cone Beam CT:**

Cone beam imaging technology is the latest development in conventional tomography. It produces images with better resolution at a lower cost and radiation. It is characterized by true volumetric data acquisition obtained simultaneously during one rotation of the x-ray source. It produces a 3-D image volume that can be reformatted using software for customized visualization of the anatomy. CBCT has already become an established diagnostic tool for various dental indications, such as endodontics, orthodontics, dental traumatology, apical surgery, challenging periodontal bone defects, preoperative planning of periodontal surgery, forensic odontology, and dental implant surgery including bone quality assessment\(^15\).

To compare, CBCT (Figure 5) has several advantages over Multi Slice CT in terms of increased accessibility to oral health specialists, more compact equipment, small footprint for the clinic, relatively reduced scan costs and lower radiation dose levels to the main organs of the head and neck\(^15\). The effective dosage ranges from two to eight panoramic radiographs. Better resolution is seen due to smaller individual voxels as compared to conventional CT. CBCT provides three-dimensional, multi-planar assessment of the maxillofacial skeleton and the ability to reconstruct the imaged volume in virtually any plane. For pre-surgical implant treatment planning, CBCT is used to...
evaluate both the bone quantity and quality. Unlike conventional peri-apical and panoramic radiographs, CBCT images are free of any geometric distortion or magnification. Thus, the clinician can precisely measure the height and width of the residual alveolar bone, detect any anatomic variations, and determine the proximity to vital structures, such as the maxillary sinus and neurovascular canals. Furthermore, CBCT also allows assessment of bone quality with an evaluation of cortical plate thickness, radio-density and architecture of the trabecular bone at the potential implant site. In addition to providing a subjective evaluation of these morphologic features, CBCT also provides a quantitative measure of bone quality at the potential implant site—most CBCT and third-party software allow clinicians to measure the gray values of the image voxels within a delineated region of interest (ROI)\textsuperscript{16}.

![Figure 5: CBCT](image)

Unlike single and multi-slice CT, CBCT does not represent the actual gray value expressed in HU.\textsuperscript{25}

A large amount of scattered x-rays and artifacts' have been mentioned as the reasons for unreliability of CBCT in evaluating bone mineral density.\textsuperscript{15}

Hence, there are several disadvantages of CBCT including scattered radiation, long scanning time, limited dynamic range of the X-ray area detectors and density values without a linear correlation to bone density.

**Tuned Aperture Computed Tomography (TACT):**

TACT is a new 3D radiographic technique for based on optical aperture theory. It is an alternative to film based tomography and CT. This technique uses information that is obtained by passing a radiographic beam through an object from several different angles. For dental applications a cluster of small radiograph tubes have been developed that are fired in close sequence. The relationship of the source and the object is used to determine projection geometry after the exposure is complete.

TACT (Figure 6) can map the incrementally collected data into a single 3-dimensional matrix. It can isolate images of desired structures limited to certain depths and can accommodate patient’s motion between exposures without affecting the final 3D image. It allows to adjust contrast and resolution. TACT has a number of advantages such as calculation of projection geometry after individual exposures, reduced radiation doses and ability to accommodate for patients motion. TACT can improve the clinician’s ability to detect and localize disease, important anatomical structures, and abnormalities. Studies have shown that TACT imaging is efficient to identify the location of crestal defects around dental implants and natural teeth and also can detecting subtle or recurrent decay.\textsuperscript{12} The area to look out for in the future with TACT are applications in identifying and localization of periodontal bone loss or gain, peri-apical lesion localization, changes in the temporomandibular-joint and identification of the 3-D anatomy of root canals.\textsuperscript{17}

![Figure 6: TACT](image)

**Interactive CT:**

Computerized tomography took a while to be used in dentistry, though far superior than traditional radiographic techniques. The elimination of distortion allows for increased predictability when planning implant cases. The main advantage of ICT is that it enables the clinician to perform “electronic surgery”. This enables 3D treatment plan that is integrated with the patient’s anatomy and can be visualized before the implant surgery by the clinician and the patient. In 1993 SIM/Plant\textsuperscript{™} 3D dental software program (Figure 7) for windows was developed allowing clinicians to utilize their own computers to interactively plan an implant case. The benefits of the SIM/Plant program include ability to measure bone density, identify and measure the proximity of the implant to vital structures, estimate the volume needed for a sinus graft. Further benefits include visualization of implants from a 3D perspective allowing verification of parallelism, thus reducing offset loading of implants. The full potential of the program is seen when the position of the final prosthesis is translated to the CT scan, allowing placement of to be prosthetically driven.\textsuperscript{14, 18}

![Figure 7: Interactive CT](image)
The CT is taken at any standard Tomography site which is then translated to the SIM/Plant™ program allowing interactive analysis and planning. When ready, the data is sent to Implant/Logic systems for fabrication of a surgical guide stent that aids the surgical and restorative dentist in accurate placement of the implant as planned.

Denta-Scan Imaging:

Denta-Scan (Figure 8) is a unique new computer software program which provides computed tomographic (CT) imaging of the mandible and maxilla in three planes of reference: axial, panoramic, and oblique sagittal (or cross-sectional). The clarity and identical scale between the various views permits uniformity of measurements and cross-referencing of anatomic structures through all three planes. Denta Scan has certain advantages, namely, evaluation of bone height and width, identification of soft and hard tissue pathology, location of anatomical structures and measuring vital qualitative dimensions necessary for implant placement. The main disadvantage of this imaging modality is its radiation exposure and cost.

Figure 8: Denta-Scan

Magnetic Resonance Imaging:

Magnetic resonance imaging or MRI, first described in the year 1946, is based on the phenomenon of nuclear magnetic resonance imaging (NMRI). Its application in the field of implantology is of recent origin. Its use is mostly in cases where soft tissue imaging is indicated, as a secondary imaging technique when primary imaging modalities fail, to visualize the fat in trabecular bone and to differentiate the inferior alveolar canal and neurovascular bundle from the adjacent trabecular bone.

Studies have shown that the geometric accuracy of the mandibular nerve with MRI is comparable with CT and it is an accurate imaging method for dental implant treatment planning. However MRI is not useful in characterizing bone mineralization or for identifying bone or dental diseases.

Conclusion:

There are various imaging options available in the present day scenario; however, the choice of modality should be based on individual requirements of a particular case. The skill, knowledge and ability of the clinician to interpret obtained data also play a crucial role in selection of the imaging modality. The cost of the procedure and radiation dose should also be weighed to the benefit of anticipated information.

Selection of the type of modality should be made keeping in mind the type and number of implants, location and surrounding anatomy.
**Summary:**
The selection of imaging modalities may be made based on the below mentioned table.<sup>24</sup>

<table>
<thead>
<tr>
<th>Imaging modality</th>
<th>Applications</th>
<th>Cross-sectional information</th>
<th>Advantages</th>
<th>Dis-advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA Radiography</td>
<td>SI, MI, RA, E</td>
<td>Not provided</td>
<td>Easily available\nGreater resolution\nCost effective\nLess distortion\nLow dose</td>
<td>Limited area imaging\nFacio-lingual dimension not recorded\nLimited reproducibility\nImage distortion</td>
</tr>
<tr>
<td>Occlusal Radiography</td>
<td>SI, MI, RA</td>
<td>Not provided</td>
<td>Easy availability\nHigh image definition\nRelatively large imaging area\nLow cost\nLow dose</td>
<td>Image superimposition\nNot much information on bucco-lingual dimension\nLess use in maxilla\nLimited reproducibility</td>
</tr>
<tr>
<td>Panoramic Radiography</td>
<td>SI, MI, RA, E</td>
<td>Not provided</td>
<td>Easy availability\nMinimal cost\nLarge imaging area\nLow dose</td>
<td>Bucco-lingual dimension not provided\nImage distortion present\nTechnique errors are common\nInconsistent horizontal magnification</td>
</tr>
<tr>
<td>Conventional Tomography</td>
<td>SI, MI, RA, E</td>
<td>Provided</td>
<td>Minimal image overlap\nLow to moderate dose\nProvides bucco-lingual information\nSimulates implant placement with use of software\nAccurate measurements</td>
<td>Technique sensitive\nLimited availability\nLess image resolution than plain films\nRequires trained personnel</td>
</tr>
<tr>
<td>Computed tomography</td>
<td>SI, MI, RA, E</td>
<td>Provided</td>
<td>Information on all sites are available\nNo superimposition\nUniform magnification\nAccurate measurements\nSimulates implant placement with use of software\nMakes interpretation more reliable and minimizes inter operator interpretation errors</td>
<td>Technique sensitive\nLimited availability\nSpecial training required\nHigh cost\nHigh doses</td>
</tr>
<tr>
<td>Cone Beam Computed Tomography</td>
<td>SI, MI, RA, E</td>
<td>Provided</td>
<td>Better image resolution\nLower dose than CT\nLower cost than CT\nSimulates implant placement with use of software\nEasy availability\nCompact equipment\nImages with better resolution\nMinimal distortion and magnification\nMakes interpretation more reliable and minimizes inter operator interpretation errors</td>
<td>Does not represent the actual gray scale value\nBone density cannot be evaluated because of X-ray scattering\nLonger scanning time</td>
</tr>
<tr>
<td>Tuned Aperture Computed Tomography</td>
<td>SI, MI, RA, E</td>
<td>Provided</td>
<td>Low Dose\nCost efficient\nIs of greater diagnostic value\nContrast and resolution of image can be adjusted\nAccommodates patient motion between exposures</td>
<td>Technique sensitive\nLimited availability\nSpecial training required\nLow quality of images</td>
</tr>
<tr>
<td>Denta Scan</td>
<td>SI, MI, RA, E</td>
<td>Provided</td>
<td>Bone height and width is obtained\nIdentification of soft and hard tissue pathology\nAnatomical structures can be located\nMeasuring vital qualitative dimensions necessary for implant placement.</td>
<td>Radiation exposure\nExpensive</td>
</tr>
</tbody>
</table>
Reference


