REVIEW ARTICLE

Diagnostic Imaging in Implant Dentistry

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Abstract

Dental implants have revolutionized the field of dentistry. Its immense popularity and wide acceptance has led to a point, where it has become a part of routine treatment plan in oral rehabilitation. For the success of implants, a presurgical treatment planning is of utmost importance. To aid this, diagnostic imaging plays a vital role. There are various modalities of imaging which will aid in placing the implant in an appropriate location with relative ease and also get a predictable outcome. This article focuses on the various imaging modalities available currently and their clinical applications. Modalities described are intraoral radiography, cephalometric radiography, panoramic radiography, conventional tomography, computed tomography, cone-beam CT and magnetic resonance imaging. The final selection of one these imaging modalities are dependent on the operator choice based on the patients need.

Keywords: Diagnostic imaging, Magnetic resonance imaging, Cone-beam CT, Dentascan.

Dental implant technology has undergone dramatic changes in the past few years and has become a significant treatment planning option in restorative dentistry. Long-term success rates are reported to approach 95% or more. In the past, success has been attributed to increasingly sophisticated imaging technology that has been applied to all phases of implant therapy.[19]

Successful implant imaging must recognize that the imaging as well as implant process is prosthetically driven. Because the ultimate objective of fixture placement is a fundamental esthetic and maintainable restoration,[16] no imaging technique is perfect with each examination carrying some risk of false negative or false positive results. Therefore, the patient’s specific needs must be carefully considered.[13-15] It is indeed a disservice to the patient to use recommended imaging technique based on only consideration of radiation dose, cost or proprietary interest.[16]

Several imaging techniques are currently available for presurgical and postsurgical examination.[12] These may vary from simple two-dimensional views such as panoramic radiographs to more complex views in multiple planes depending on the case and experience of the practitioner. This article focuses on various imaging modalities available, its advantages and disadvantages for its application in implant dentistry.

SELECTION OF A RADIOGRAPHIC METHOD

There are a number of basic principles of radiography that should guide the clinician in selecting an appropriate imaging technique.[12]

- There should be adequate number and type of images to provide the needed anatomic information.
- The type of imaging technique selected should be able to provide the required information with adequate precision and dimensional accuracy.
- There must be a way of relating images to the patient anatomy.
- In whatsoever technique used, the patients X-ray beam and imaging receptor should be positioned to minimize distortion.
- The imaging information should balance with the radiation dose and financial cost to the patient.[12] The ALARA principle should govern the selection if more than one technique is feasible.[18] The ALARA (As Low As Reasonably Achievable) philosophy recognizes that, no matter how small the radiation dose, some adverse

effect may result. Consequently any dose that can be reduced without difficulty, great expense, or inconvenience should be reduced.[19]

The quality of bone in the proposed implant site in terms of relative proportion and density of cortical and medullary bone has frequently been assessed by using a grading scheme proposed by Lekholm and Zarb, which is applicable only to cross sectional images. In this the alveolar bone is divided into four classes.[7](1) Almost the entire jaw bone is composed of trabecular bone; (2) A thick layer of compact bone surrounding a core of dense trabecular bone; (3) A thin layer of compact bone surrounding a core of dense trabecular bone of favorable strength; (4) A thin layer of compact bone surrounding a core of low density trabecular bone.

Lindh et al proposed a new bone quality classification based on periapical radiographs that grade the medullary bone only as having dense, sparse or alternating dense and sparse trabeculation. This technique does not necessitate the use of cross-sectional imaging but it is less specific than Lekholm and Zarb method.[5]

IMAGING MODALITIES

There are many imaging modalities that have been employed for implant imaging, including devices developed specifically for dental implant imaging. These modalities can be described as either analog or digital and two-dimensional or three-dimensional.[18]

Analog imaging modalities are the periapical, occlusal, panoramic, lateral cephalometric radiographs which are two dimensional systems that employ X-ray film and/or intensifying screens as the image receptors.[18]

Digital imaging include the computed tomography, tuned aperture computed tomography, cone-beam CT, magnetic resonance imaging. These create a three-dimensional image which is described not only by its width, height and pixels, but additionally by its depth and thickness.[18]

Intraoral Radiography

Intraoral periapical and occlusal radiography provide images of perhaps the greatest details of any imaging technique. They are used in initial phase of patient evaluation to detect the presence of pathosis, the approximate location of anatomic structures such as maxillary sinus and also estimate the quality of the trabecular bone.

When periapical radiographs are used, it is important to ascertain certain guidelines. It is paramount that exposure be made using paralleling angle technique. Excessive base fog, improper exposure factor and poor processing should be avoided. However, because the film plane can rarely be placed parallel particularly in edentulous areas, the target film distance is difficult to standardize. Hence, periapical radiographs do not provide an accurate assessment of vertical bone dimension or precise position of critical anatomic structures.[12] It is reported that only 53% of measurement from alveolar crest to superior wall of mandibular canal were accurate within 1 mm. By comparison, 94% of all measurement made from CT images were accurate within 1 mm.[12]

Direct digital intraoral imaging is emerging as an alternative to film based radiography.[4] Its advantages include rapid acquisition of images, their storage, retrieval, and tramission to remote sites. As the images got through this is similar to that of the film based radiography, it faces the similar limitations. Hence its use is dependent on the operator’s ability to manipulate image density and contrast to measure the bone density at specific sites and to use it further for treatment planning.[12]

As periapical radiographs are unable to provide a cross sectional information, occlusal radiographs are sometimes used to determine the faciolingual dimensions of the mandibular alveolar ridge. Although somewhat useful, the occlusal image records only the widest portion of the mandible which is located inferior to the alveolar ridge. This may give the clinician a wrong impression that more bone is available in the cross-sectional dimension than that actually exists. The occlusal technique is not useful in maxillary arch because of anatomic limitations.[19]

Cephalometric Radiography

Lateral and lateral oblique (45*) cephalometric projections provide information of the maxillary and mandibular alveolar process in the mid sagittal plane.[3,19] These projections provide image of known magnification (7-12%).[19] The soft tissue profile is also apparent on this film and can be used to evaluate profile alterations after prosthodontic rehabilitation. The vertical dimension of alveolar process in the posterior region may be obtained by rotating the patients head such that the body of the mandible is parallel with the plane of the film. Because a cross sectional view of the jaws is obtained only in the anterior of midline, the use of this technique for measurement of the horizontal dimension of alveolar process is applicable only to this area.[26]

Panoramic Radiography

Although the resolution and shape of panoramic radiograph is less than that of an intraoral film, panoramic projection provides a broader visualization of the jaws and adjoining anatomic structures.[19] The panoramic imaging is unique because the magnification in the vertical plane is relatively stable but the magnification in the horizontal plane is highly variable[12] which is attributed to the focus of projection. In vertical plane, the efficient source of projection is the focal spot on the X-ray tube whereas in horizontal plane, it is the rotational centre of X-ray beam.[8,9] Hence magnifications in the horizontal plane vary considerably because of the constantly changing distance between the rotational center and the film and the changing rate of movement of the film to that of X-ray beam.[8,9]

Information from panaromic radiography must be applied judiciously as the angular measurements tend to be accurate but linear measurement is not.[3] In addition, vertical measurements are unreliable because of foreshortening or elongation of the anatomic structures since the X-ray beam is not perpendicular to the long axis of anatomic structures or the film plane. The negative vertical angulations of the X-ray beam also may cause lingually positioned objects such as, mandibular tori to be projected superiorly on the film which may result in an overestimation of vertical bone height (Fig. 1).[19]

Several attempts have been made to overcome these limitations such as the use of surgical stents containing metal balls of known dimensions. Although this may mitigate some of the magnification errors, it does not overcome all limitations, including the lack of cross-sectional imaging.[12]

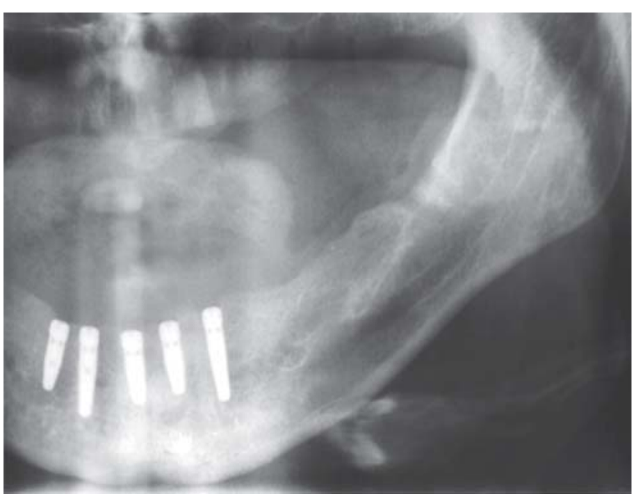

Fig. 1: Panoramic radiograph of the mandible demonstrates successful osseointegration of five fixtures

THREE DIMENSIONAL IMAGING

A three-dimensional treatment plan ideally identifies at each prospective implant site, the amount of bone width, the ideal position and orientation of each implant, its optimal length and diameter, the presence and amount of cortical bone on the crest, the degree of mineralization of trabecular bone and the position or relationship of critical structures to the proposed implant sites. Thus, the modalities of choice for implant treatment planning provide high resolution and dimensionally accurate three dimensional information about the patient at the proposed implant site.[18]

Conventional Tomography

It is a technique designed to obtain clearer images of the structures lying within a plane of interest. In this, the X-ray beam and film move with respect to each other blurring out structures not in the desired imaging plane.[12] The thickness, orientation and the anatomic location of the image layer can be predetermined and manipulated. Scout films (usually submentovertex, occlusal or panoramic projection) or wax bite registrations or orientation laser light are used to determine the appropriate cross-sectional angulation.[19] The closer and perpendicular the anatomic long axis of a structure is located relative to the path of tube travel, the more its image will be blurred and greater will be the resolution at the layer of interest.

The most basic tomographic tube film is linear, but this type of image typically has streak artefacts known as 'parasite lines'. Complex motions such as circular hypo cylinder and octospiral creates a clearer and pleasing image.[3,18] The magnification factor of conventional tomographic images is constant in all directions. It may also vary with different manufacturers but as long as it is known, it is not a problem. Conventional tomography is appropriate for planning single implant sites or for those within a single quadrant.[12,19]

Computed Tomography[20-36]

It is an advanced imaging technique in which images are acquired digitally and subsequently reformatted into any plane, such as axial, sagittal or coronal.[1,2,20-25,27-34,40] Typically, a narrow X-ray beam is used to scan a patient at right angles to the long axis of the body.[16,26] These axial images are thin (1-2 mm) and overlapping resulting in approximately 30 axial images per jaw. The image information of these sequential axial images can be manipulated into various planes using computer based process called multiplanar reformatting (mpr) (Fig. 2).[19] The contrast of these images depends on the quality of the

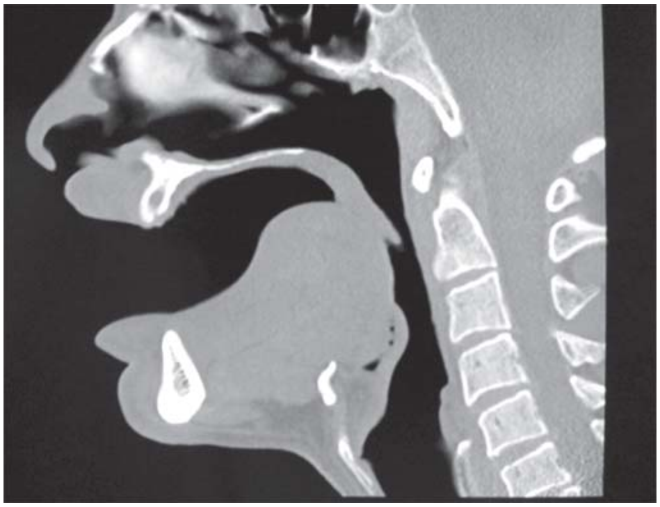

Fig. 2: Multiplanar reformatted images obtained by CT. Anatomic position of each cross-sectional image are located by numbers

X-ray beam, the tissue density and characteristics of the detectors used to measure the transmitted energy. CT images can capture upto 200 gray levels. Since the human eye cannot perceive or interpret so many gray levels at once, they are shown in segments that are weighed to favor the demonstration of either hard or soft tissue. Image detail or spatial resolution depends largely on the quality of the X-ray detectors, the quality of the display and the amount of radiation.

Reformatted images can be transferred to film, photographic paper or other materials. It is possible to print images in life size so that they are faithful and accurate representations of patients. It is also possible to display the CT numbers or Hounsfield units in selected regions of interest. These images requiring additional processing is done on the CT console.[16] It is also possible to transfer the CT data to study models.

The advantages of CT[12] based systems are (1) uniform magnification; (2) high contrast image with well-defined image layer free of blurring; (3) easier identification of bone grafts or hydroxyappatite materials used to augment maxillary bone in sinus region; (4) multiplanar views; (5) three-dimensional reconstruction; (6) simultaneous study of multiple implant sites; (7) availability of soft tissue for image analysis.

The disadvantages include (1) limited availability of reconstructive software; (2) higher dose of radiation; (3) lack of understanding of dentists need by the radiologic technologist; (4) lack of usefulness for implant interface follow-up because of metallic streak artifacts; (5) expense.[19]

Computed Tomosynthetic Radiography: Tuned Aperture CT (TACT)

An alternative to film based tomography and CT for dentoalveolar imaging is a method based on optical aperture theory, referred to as TACT. This technique uses information collected by passing a radiographic tube that can be fixed in close sequence. The relationship of the source and the object can be used to determine projection geometry after the exposure is complete. TACT can map the incrementally collected data into a single three-dimensional matrix. TACT offers a number of advantages because projection geometry can be calculated after individual exposures, problems of patient movement are also less significant and radiation doses are comparatively low. Studies suggest that TACT imaging can efficiently identify the location of crestal defect around implant fixtures and natural teeth in addition to detecting subtle or recurrent decay.[16]

Cone Beam Computed Tomography (CBCT)

One of the novel developments in CT imaging technology is cone beam imaging, which not only reduces the size and cost of CT scanners but also improves the resolution of the image with lesser amount of radiation dose than that used in CT scans. This technology yields images with isotropic submillimeter spatial resolution; as a result, its use is suited perfectly for dental and maxillofacial cases.[48] The first commercial CBCT introduced was the NewTom DVT 9000 (Quantitative Radiology, Verona, Italy) devoted to maxillofacial imaging. The latter models currently in market are NewTom 3G, I-CAT (Imaging Sciences International, Hatfield, USA), 3D Accuitomo (J Morita, Kyoto, Japan), PSR 900N (Asahi Roentgen, Koyoto, Japan), CB MercuRay (Hitachi Medico Technology Corporation, Kashiwa, Chiba, Japan).[37-39]

Studies comparing the reliability of CT and CBCT by Kobayashi et al have confirmed the superiority of PSR 9000 Cone Beam CT to spiral CT in terms of spatial resolution on cross-sectional images. CBCT is devoted to maxillofacial area to scan and visualize jaw bone lesions especially cancellous bone. This technology offers the surgeon precise views of preplanned locations in the patients jaw (Figs 3 and 4).[17] It is perhaps, when employed as a means for developing surgical guides for implant dentistry that, cone beam CT scanning finds one of its best uses and helps in accurate transfer of preoperative plan to the patient.[37-39]

Fig. 3: A Cone-beam computerized tomography image of mandible shown in 3-dimensions

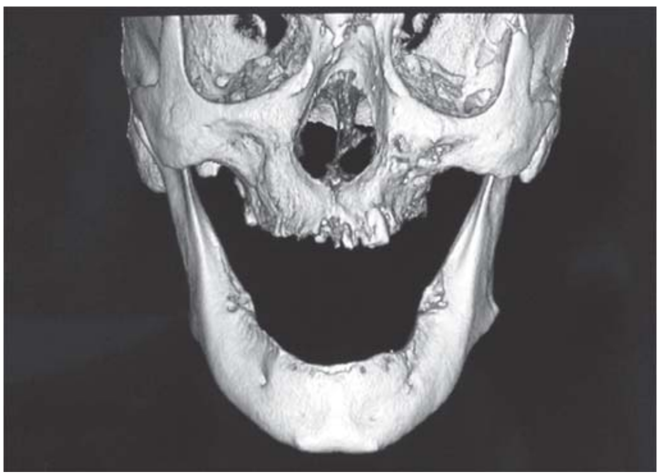

Fig. 4: A Cone-beam computerized tomography image of the entire maxillofacial region

Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging has been proposed as an appropriate imaging technique for dental implants.[45] It has a major advantage of minimizing the patient risk because no ionizing radiation is being used.[3] MRI is based on the phenomenon of nuclear magnetic resonance where in signals from hydrogen nuclei (protons) in water and fat are used to form cross-sectional images of the body. Lauterbur (1973) developed the imaging principle which allows us to construct the MR image for which strong uniform static magnetic field, switched magnetic field gradients; with radiofrequency magnetic field pulses are used.[42-44] The molecular environment and the proton densities influence the relative intensities of MR signals produced. The signals from the hydrogen protons in water and fat vary depending on the nature of tissue being examined. Most MRI operate in the mid- field range (approximately 0.5-1.5 Tesla, where 1 Tesla is around 20,000 times the strength of the earth's magnetic field).[46,47]

Mid-field scanners usually require the subject to be imaged within a tunnel which may cause claustrophobia but the novel low-field scanner designs allow the subject to be imaged with an open magnet, which offers a less claustrophobic imaging environment. Images are often described as being T1or T2 which refers to longitudinal and transverse proton relaxation times respectively. In general, T1 weighted images are used to show normal anatomy while T2 weighted images are useful for detecting infection, hemorrhage and tumors[46]. MRI especially with 0.2 Tesla low field scanner has shown definite potential as a future replacement for CT imaging.[12,4]

INTERACTIVE SOFTWARES

Several different software packages have been developed. The software is available for both computed tomography (SURRLAN) and reformatted computed tomography (Denta Scan, SimPlant). Other softwares like Procera Software (Nobelbiocare, Sweden, Vimplant (CyberMed, Seoul, Korea) are also available. These programs provide an interactive platform permitting analysis of potential implant sites for bone quantity, quality and morphology.[19,46]

IMAGING STENTS

Presurgical imaging can be enhanced by the use of an imaging stent that helps relate radiographic image and its information to a precise anatomic location or potential surgical site. The implant sites can be identified by radiographic spheres or rods retained within an acrylic stent. These can subsequently be used as a surgical guide to orient the insertion angle of the guide bar and ultimately the angle of the implant. Since the metallic markers produce artifacts in CT, only nonmetallic radiopaque markers, e.g. gutta-percha, composite resins are to be used.[18,19]

SUMMARY

Diagnostic imaging and techniques develop and implement a cohesive and comprehensive treatment plan. Clinicians however must recognize that each technique has advantages and limitations. Cross-sectional imaging is increasingly considered as essential for optimal implant placement especially in case of complex reconstruction but the question of which technique to apply remains for the clinician to answer carefully considering all variables.

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