Role of Radiographic Evaluation in Treatment Planning for Dental Implants: A Review

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Abstract
Objectives: This review has been done with the objective of evaluating different imaging modalities available to the dental practitioners in treatment planning for implant placement. Material and Methods: A systematic online search was conducted with relevant keywords. The inclusion criteria was all articles that discussed 2-dimensional and 3-dimensional imaging modalities that have been introduced for pre, peri & post operative implant surgery. Textbooks relevant to the topic were also hand searched. The data obtained has been included in the discussion and summarized as per the available literature. Conclusion: The evolution of implant imaging modalities from simple 2-dimensional to complex 3-dimensional techniques have improved the sensitivity & specificity with which a favorable implant site may be located preoperatively, its location (in all the three planes) more objectively assessed peri operatively and the prognosis of the implants followed more accurately. Yet the more complex modalities are more technique sensitive & their high radiation dosage require more rigorous justification for routine usage.

Key words: Lateral cephalometric radiographs, Panoramic radiography, Computed tomography, CBCT, MRI

Introduction
Selection of ideal implant site as well as optimal implant for a particular site is the first step in achieving functionally and esthetically successful implant prosthesis. Diagnostic imaging plays an important role in evaluating the dental implant patient.¹ These examinations depict & quantify accurate bone height, width & contour and also provide information about the locations of vital anatomic structures, adjacent to the sites of implant placement. The choice of radiologic technique appropriate for a given patient depends on a number of factors, including the type of implant to be used, the position of the remaining dentition and the extent to which bone quality or quantity is in question. A thorough radiographic assessment is paramount for evaluating these factors and informing patients of their prospects for successful rehabilitation as well as in judging and guiding implant placement peri operatively and evaluating implant prognosis post operatively.

Imaging studies can include basic plain radiography (periapical, occlusal) as well as advanced studies such as computed tomography (CT) and reformatted cross-sectional, 3D imaging. The intent of this article is to provide an overview of different techniques available in the evaluation of the dental implant patient both pre and postoperatively.²

Materials & Methods
A systematic online search was conducted with relevant keywords. The inclusion criteria included all articles that discussed 2-dimensional and 3-dimensional imaging modalities that have been introduced for pre, during & post operative implant surgery. Textbooks relevant to the topic were also hand searched. The data obtained have been included in the discussion and summarized as per the available literature.

Imaging Modalities
The decision to image the patient is based on patient's clinical needs. Once a decision to image the patient has been made, the required modality is employed, that yields the necessary information related to the patient's clinical needs and results in the least radiological risk.

Some of the imaging modalities that have been reported as useful for dental implant imaging include: periapical, panoramic, occlusal, cephalometric and tomographic radiography, computed tomography, magnetic resonance imaging and interactive computed tomography.

These imaging modalities can be described as either analog or digital and two dimensional or three dimensional.

Periapical Radiography
Periapical radiographs are images of a limited region of the mandibular or maxillary alveolus. Periapical radiographs are produced by placing the film intra-orally parallel to the body of the alveolus with the central beam of the X-ray device perpendicular to the alveolus at the region of interest, producing a lateral view of the alveolus.

Advantages
In the pre-prosthetic phase, these films are most often used for single tooth implants in regions of abundant bone width.
These are well suited for documentation and assessment of possible peri-implant bone resorption during follow-up.

**Limitations**

It is of limited value in determining quantity because the image is magnified, may be distorted, and does not depict the third dimension of bone width. It is of limited value in determining bone density or mineralization.

**Occlusal Radiography**

Occlusal radiographs are planar radiographs produced by placing the film intra orally parallel to the occlusal plane with the central x-ray perpendicular to the film for the mandibular image and oblique (45°) to the film for maxillary image.

**Advantages**

Because periapical radiographs are unable to produce any cross sectional information occlusal radiographs are sometimes used to determine the facio lingual dimensions of the mandibular alveolar ridge.

**Limitations**

Maxillary occlusal radiographs are inherently oblique and are so distorted that they are of little quantitative use for implant dentistry, for either determining the geometry or the degree of mineralization of the implant site. In addition, it shows the widest width of bone (i.e. the symphysis) versus the width at the crest, which is where diagnostic information is needed most.

**Lateral Cephalometric Radiographs**

Cephalometric radiographs are oriented planar radiographs of the skull. The skull is oriented with respect to the x-ray device and the image receptor using a cephalometer, which physically fixes the position of the skull with projections into the external auditory canal. The geometry of cephalometric imaging devices results in 7 to 12% magnification of the image.

**Advantages**

The lateral cephalometric radiograph is useful because it demonstrates the geometry of the alveolus in the anterior region and the relationship of the lingual plate to the patient's skeletal anatomy.

**Limitations**

This technique is not useful for demonstrating bone quality and only demonstrates a cross-sectional image of the alveolus where the central rays of the x-ray device are tangent to the alveolus. Other disadvantages include image magnification and superimposition.

**Panoramic Radiography**

Panoramic radiography is a curved plane tomographic radiographic technique used to depict the body of the mandible, maxilla, and the lower one half of the maxillary sinuses in a single image. This radiographic technique produces an image of a section of the jaws of variable thickness and magnification.

**Advantages**

Gross anatomy of the jaws and any related pathologic findings can be evaluated. Diagnostic templates that have 5 mm ball bearings or wires incorporated around the curvature of dental arch are worn by the patient during the panoramic x-ray examination, enables the clinician to determine the amounts of magnification in the radiograph.

**Limitations**

Assessments of mesiodistal distance can be very imprecise due to inappropriate patient positioning and/or individual variations in jaw curvature. It is of limited value in demonstrating critical structures but is of very little use in depicting the spatial relationships between the structures and dimensional quantification of the implant site.

**Tomography**

The basic principle of tomography is that the x-ray tube and film are connected by a rigid bar called the 'fulcrum bar' which pivots on a point called the fulcrum. When the system is energized, the x-ray tube moves in one direction with the film plane moving in the opposite direction and the system pivoting about the fulcrum. The fulcrum remains stationary and defines the section of interest, or the tomographic layer. Different tomographic sections are produced by adjusting the position of the fulcrum or the position of the patient relative to the fulcrum in fixed geometry systems. Circular, spiral and hypocyclocidal are tube motions employed in complex tomography.

**Advantages**

High-quality complex motion tomography demonstrates the alveolus and taking magnification into consideration enables quantification of the geometry of the alveolus. This technique also enables to determinate the spatial relationship between the critical structures and the implant site. Postimaging digitization of tomographic implant images enables use of a digital ruler to aid in the determination of alveolar bone for implant placement. Image enhancement can aid in identifying critical structures such as the inferior alveolar...
Complex tomography is not particularly useful in determining bone quality or identifying bone and dental disease.

Computed Tomography (CT)
Computed tomography (CT) is a digital and mathematical imaging technique that creates tomographic sections where the tomographic layer is not contaminated by blurred structures from adjacent anatomy. Most importantly, computed tomography enables differentiation and quantification of both soft and hard tissues.

Advantages
CT provides a unique means of imaging analysis of proposed surgery or implant sites by reformatting the image data to create tangential and cross-sectional tomographic images of the implant site.

With current generation CT scanners, reformed images are characterized by a section thickness of 1 pixel (0.25 mm) and an in-plane resolution of 1 pixel by the scan spacing (0.5 to 1.5 mm) producing a geometric resolution similar to that of planar imaging. The density of structures within the image is absolute and quantitative and can be used to differentiate tissues in the region and characterize bone quality.

The advantages of this type of imaging are evident and the limitations of delivery clear, which was spawned the development of a number of techniques, referred to generically as 'Dentascan Imaging'.

Dentascan Imaging
Dentascan imaging provides programmed reformation, organization, and display of the imaging study. It indicates the curvature of the mandibular or maxillary arch and the computer is programmed to generate referenced cross-sectional and tangential/panoramic images of the alveolus along with three-dimensional images of the arch. The cross-sectional and panoramic images are spaced 1 mm apart and enable accurate preprosthetic treatment planning. Usually, a diagnostic template is necessary to take full advantage of the technique.

Advantages
This technique provides a wealth of diagnostic information that is accurate detailed and specific. CT enables identification of disease, determination of bone quantity and quality, identification of critical structures at the proposed regions, and determination of the position and orientation of dental implants.

Limitations
Images may not be of true size and may require compensation for magnification. Determination of bone quality requires use of the imaging computer workstation. Hard copy Dentascan images only include a limited range of the diagnostic gray scale of study; and the tilt of the patient's head during the examination is critical because all the cross-sectional images are perpendicular to the axial imaging plane.

Interactive Computed Tomography (ICT)
Interactive computed tomography addresses many of the limitations of CT. ICT was developed to bridge the gap in information transfer between the radiologist and the clinician. This technique enables radiologist to transfer the imaging study to the clinic, computer file and enables the clinician to view and interact their own computer.

Advantages
ES and ICT enables the development of a three-dimensional treatment plan that is integrated with the patient's anatomy and can be visualized before implant surgery by the members of the implant team and the patient for-approval or modification. ICT enables the determination of bone quality adjacent to the prospective implant sites. It helps to determine the number and size of implants accurately along with the density of bone at the proposed implant sites.

Limitations
At this time ICT is the most accurate imaging technique for implant imaging and surgery but suffers some limitations. ES enables placement of electronic implants in the imaging study but the refinement and exact relative orientation of the implant positions is difficult and cumbersome.

Magnetic Resonance Imaging (MRI)
MRI is a three-dimensional imaging technique with an electronic image acquisition process and a resulting digital image. This is a technique to image the protons of the body by employing magnetic fields, radio frequencies, electromagnetic detectors, and computers.

Advantages
Like CT, MRI is a quantitatively accurate technique with exact tomographic sections and no distortion.

Limitations
MRI is not useful in characterizing bone mineralization or as a high-yield technique for identifying bone or dental disease.

Reformatted Cone-Beam and Multi Detector Computed Tomography (CBCT & MDCT)
Patients who are edentulous or who are being considered for multiple implant placement may be best imaged by these techniques. The jaws are aligned so that the acquired axial computed tomographic image slices are parallel to the occlusal plane. These axial images are thin (1-2mm) and...
overlapping, resulting in approximately 30 axial image slices per jaw. The image information of these sequential axial images can be postprocessed to produce multi two-dimensional images in various planes, using a computer-based process called multiplanar reformatting (MPR).

**Advantages**

Typical computed tomographic studies provide information on the continuity of the cortical plates, residual bone in the maxilla and mandible, the relative location of adjoining vital structures, and the contour of soft tissues covering the osseous structures. Reformatted images from CBCT data have been shown to be of equivalent measurement accuracy as MDCT data. These reformations are useful in planning augmentation procedures such as a sinus lift and can provide an estimate of the internal density. A three dimensional image can provide a visualization of the overall morphology of the intended implant site.

**Disadvantages**

Metallic restorations can cause streak artifacts but this can be avoided by aligning the jaws so that the acquired axial scans are parallel to the occlusal plane.

**Discussion**

The objectives of diagnostic imaging depend on a number of factors, including the amount and type of information required and the time period of the treatment rendered. Successful implant placement and osseointegration normally require 1 - 1.5 mm of bone on either side of the fixture and 1 - 2 mm of bone between the base of the fixture and adjacent structures such as the nasal fossa, floor of the maxillary sinus, mandibular canal, and inferior border of the mandible. When evaluating the alveolar ridge, the radiologist should also determine the angle the ridge makes with the vertical axis. This is important because the occlusal force vector acting on the fixture should be parallel, or as near parallel as possible, to the vertical axis through the alveolar ridge. If excess angulations should exist between the vertical axis through the fixture and that through the alveolar ridge, the resultant force vector may fall in an area unable to withstand occlusal forces and breakdown of the surrounding bone may occur.

Another important aspect of the radiologic evaluation should be a qualitative description of the bone in a given area. Optimal osseointegration occurs only in certain types of bone. Although there is no universally accepted system for classifying bone quality in the maxilla and mandible, the Misch system is commonly used in evaluating cross-sectional reformatted images and that system is used in the ensuing discussion.

The decision to image and determine which imaging modality to use depends on the integration of these factors and can be organized into the following three phases:

**Phase one-Pre prosthetic Implant imaging**

This phase involves all past radiologic examinations along with new radiologic examinations chosen to assist the implant team in determining the patient's final and comprehensive treatment plan. The objectives of this phase of imaging include all necessary surgical and prosthetic information to determine the quality and quantity and angulations of bone; the relationship of critical structures to the prospective implant sites; and the presence or absence of disease at the proposed surgery sites.

**Phase two-Surgical and Interventional Implant imaging**

This phase is focused on assisting in, the surgical and prosthetic intervention of the patient. The objectives of this phase of imaging are to evaluate the surgery sites during immediately after surgery, assist in the optimal position and orientation of dental implants, evaluate the healing an integration phase of implant surgery, and to ensure abutment position and prosthesis fabrication are correct.

**Phase three-Post prosthetic Implant imaging**

It commences just after the prosthesis placement and continues as long as the implants remain in the jaws. The objectives of this phase of imaging are to evaluate the long term maintenance of implant rigid fixation and function including the crestal bone levels around each implant and evaluate the implant complex.

The various methods elaborated here have their unique characteristics and each of these applied judiciously where required helps the diagnostician as well as the clinician to accurately plan, execute and evaluate implant treatment.

Periapical radiographs produce a high resolution planar image of a limited region of the jaws. Periapical radiographs do not provide any cross-sectional information of the jaws and may suffer from both distortion and magnification. However, the long cone paralleling technique eliminates distortion and limits magnification to less than 10%.

Occlusal radiography produces high resolution planar images of the body of the mandible or the maxilla. Cephalometric radiographs are a useful tool for the development of an implant treatment plan, especially for the completely edentulous patient or for placement of implants near the midline for overdentures.

Tomographic sections spaced every 1 or 2 mm enable evaluation of the implant site region and appreciation of the three-dimensional appearance of the alveolus. The quantity of alveolar bone available for implant placement can be determined by compensating for magnification. Dentascan is
capable of determining all five radiologic objectives of pre-prosthetic implant imaging: identify disease, determine bone quality and quantity, determine implant position and implant orientation. An important feature of ICT is that the clinician and radiologist can perform electronic surgery (ES) by selecting and placing arbitrary size cylinders that simulate root form implants in the images. With an appropriately designed diagnostic template, ES can be performed to electronically develop the patient's treatment plan in three dimensions.

MRI is used in implant imaging as a secondary imaging technique where primary imaging techniques such as tomography, CT or ICT fail. MRI visualizes the fat in the trabecular bone and differentiates the inferior alveolar canal and neurovascular bundle from the adjacent trabecular bone. Oriented MRI imaging of the posterior mandible is dimensionally quantitative and enables spatial differentiation between critical structures and the proposed implant site.

Ridge augmentation procedures may be best imaged with either CBCT or MDCT to investigate all possible implant sites. These reformatted images provide the clinician with accurate two-dimensional diagnostic information in all three dimensions.

Conclusion
The imaging modalities discussed in this article range from planar imaging modalities which are simply 2-dimensional projections of the patient's anatomy to complex three-dimensional imaging modalities. The two-dimensional modalities are readily available, cost effective with least radiation exposure, but have limitations of magnifications and superimpositions and it is not possible for the clinician to develop a 3-dimensional perspective of patient's anatomy with a single image. However in complex cases in which patient's medical history indicates significant medical problems or a clinical examination shows diminished bone or other anatomical areas of concern, a more extensive and advanced radiographic evaluation is warranted. Hence cross-sectional imaging is increasingly considered essential for optimal implant placement, especially in complex reconstructions.1,2

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References