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Imaging modalities for preoperative assessment in dental implant therapy: an overview

ABSTRACT

Preoperative assessment of patients for dental implant therapy often requires extensive radiographic examination. Many imaging modalities have been reported to be useful including periapical, panoramic, lateral cephalometric and tomographic radiography, computed tomography, interactive computed tomography, and magnetic resonance imaging. This paper reviews various imaging techniques, their applications and limitations in dental implant treatment planning.

Key words: Cone-beam computed tomography; Dental implants; Diagnostic imaging; Radiography

Introduction

The placement of dental implants requires meticulous planning and careful surgical procedures. A combination of a limited bone volume and poor bone quality may lead to less predictable bone apposition and early implant failures. A thorough radiographic assessment is paramount for evaluating these factors and informing patients of their prospects for successful rehabilitation with dental implants.

A preoperative radiographic evaluation aims to identify pathological lesions, assess the quantity and quality of the alveolar bone, identify critical structures at the potential implant sites, and determine the orientation of the implants. Bone quantity and quality will influence the choice of implants with respect to their number, diameter, length and type.

Preoperative radiographic assessment has assumed an increasingly important role in treatment planning for implant-supported prostheses. It often requires a more extensive radiographic examination than that used for other types of oral rehabilitation. Many imaging modalities have been reported to be useful for dental implant therapy, including periapical, panoramic, cephalometric and tomographic radiography, computed tomography (CT), interactive CT, and magnetic resonance imaging (MRI)¹⁻⁴.

Periapical radiography

Periapical radiographs are produced by placing the film intraorally, parallel to the body of

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the alveolus, with the collimated parallel beam of the X-ray perpendicular to the alveolus at the region of interest, thus producing a lateral view of the alveolus.

Unscreened radiographs provide high-resolution (more than 20 line pairs per mm) and sharp images, which allow accurate measurements in the horizontal direction, specifically measuring the proximity of adjacent tooth roots. These are well suited for documentation and assessment of possible peri-implant bone resorption during follow-up and are considered superior to panoramic radiography in this respect ¹. With proper positioning techniques, periapical radiographs give minimum magnification and distortion and the reproducibility of these radiographs is high.

Nevertheless, the size of the film is often inadequate for the depiction of all the anatomic borders of interest for pre-implant examinations. An edentulous alveolar ridge may not have the same long axis as a tooth; the image of the alveolar bone in the region of interest may be distorted, either foreshortened or elongated. It provides only a lateral view of the selected potential implant site without cross-sectional information, and the projections are not always perfect due to problems with film placement in resorbed jaws. This can cause inaccurate measurements in intraoral radiographs ². Nonetheless, periapical radiographs show the most accurate position of the mandibular canal, with 53% of measurements being within 1 mm of the true value ^{3,4}.

Panoramic radiography

These are narrow beam rotational tomographs, which use two or more centers of rotation to produce an image, with a predefined focal trough, of both the upper and lower jaws. Panoramic radiography allows complete visualization of the relationship of the maxillofacial structures within the focal trough, and provides information on the relative position of the inferior alveolar canal and the maxillary sinuses in relation to the crest of the alveolar ridge. It provides an approximation of bone height and vital structures and any pathological conditions that may be present ¹ (Figure 1).

The major disadvantages of panoramic radiography are an unpredictable distortion of the visualized structures and a low level of reproducibility. Magnification in panoramic radiographs occurs in both vertical and horizontal directions



Figure 1 Panoramic radiograph showing radiographic markers

and varies considerably (1.1-1.7 times). The vertical magnification is relatively consistent with object depth because of a constant focus-film distance. The horizontal magnification also varies considerably because of the constantly changing distance between the rotational center and the film relative to that of the X-ray beam ⁵. Non-uniform magnification may be up to 25%; magnification of 10% in the vertical direction and 16% in the horizontal direction has been reported ⁶. Accurate assessment of hard tissue morphology and density is impossible because of the variable distortions occurring in different parts of the radiograph ⁷.

A panoramic image cannot provide clinicians with information about the buccolingual cross-sectional dimension or the inclination of the alveolar ridge ⁸. Angular measurements taken from panoramic radiographs tend to be accurate, but this is not true for linear measurements ⁹. Assessments of mesiodistal distance can be very imprecise due to inappropriate patient positioning and/or individual variations in jaw curvature ¹⁰. The focal trough of panoramic radiography is relatively thick, approximately 20 mm in the posterior region and 6 mm in the anterior region ¹¹. Moreover, the maxillary and mandibular anterior regions often appear blurred. Due to the use of an intensifying screen to reduce the radiation dosage, panoramic radiographs provide inferior images. A study into panoramic radiograph measurements by Klinge *et al.* ³ found that only 17% of measurements made from the crest of the alveolar ridge to the most superior border of the mandibular canal were accurate within 1 mm.

Although panoramic radiographs may provide a useful overview and may be used in conjunction with ridge mapping or other diagnostic tools, they are unlikely to meet the strict criteria set for primary imaging tests for implant planning ¹².

Cephalometric radiography

Lateral cephalometric radiographs are produced with the patient's midsagittal plane oriented parallel to the image receptor by using a cephalometer. The cephalometer physically fixes the position of the skull with projections into the external auditory canals.

Lateral cephalometric radiographs have been recommended for evaluating the anterior maxilla and mandible for dental implant placement¹. They can accurately measure the height and width of the residual bone at the anterior midline of both the maxilla and mandible. Lateral cephalometric radiography also allows analysis of the quality of the bony host site (ratio of compact to cancellous bone), particularly that in the anterior region of the mandible¹³. The soft tissue profile is also apparent on the radiographs and can be used to evaluate profile alterations after prosthodontic rehabilitation⁹. If a patient is already wearing a denture, a recording should be made with the denture in place in order to provide information about the preoperative relationships between the maxilla and mandible¹.

Lateral cephalometric radiographs offer limited information about the symphyseal area, and the inclination and buccolingual dimensions of the anterior jawbone region. They are not very useful when planning placement of implants lateral to the mid-sagittal plane. Moreover, due to the presence of genial tubercles, lateral cephalometric radiographs may create overly optimistic bone volume assessments¹⁴. With a fixed relationship between focus-film and film-object distance, there is a uniform magnification of about 10% (7-12%)⁹.

Lateral oblique cephalometric radiography has been proposed by Poon *et al.*¹⁵ but it is difficult to predict the amount of image magnification on these views, as the body of the mandible is not sited at the same distance from the cassette as the rotation center of the cephalostat. Thus, measurements made from these films are not reliable⁹.

Linear tomography

Cross-sectional tomographic X-ray machines produce images of slices or layers (focal plane) of the body by using the movement of the X-ray beam and film (connected by

a fulcrum bar) during an exposure to blur unwanted body parts. Linear tomographic motion is one-dimensional and produces blurring of adjacent sections in one dimension. Complex (multi-directional) tomographic motion—circular, elliptical, spiral and hypocycloidal tomography—is obtained by using the 2-dimensional movement of the tube and film and produces relatively uniform blurring of the patient's anatomy adjacent to the tomographic plane¹⁶.

Cross-sectional tomography has been successfully applied in dental implant radiography¹⁷. Cross-sectional tomographs have been shown to be more precise than panoramic radiographs when measuring the distance between the alveolar crest and the mandibular canal¹⁸. Several studies have shown that tomographic images of the posterior mandible allow better visualization of the mandibular canal than the other available radiographic techniques^{3,18}.

The disadvantage of using conventional linear tomograms is the lack of adequate cross-referencing with standard lateral, frontal, and panoramic radiographs⁷. Thus, a mental transformation is required prior to, and during, surgery. Teeth, particularly those with large metallic restorations adjacent to the area of interest, may obscure the tomographic image. Another disadvantage is limited resolution caused by use of an intensifying screen cassette, making the identification of anatomical structures and assessment of bone topography more difficult¹⁹.

Tomographic images are always magnified because of the relationships between focus-film and film-object distances. Since all the structures in the tomographic plane are at the same distance between focus and film, the tomographic images are free from distortion. They have a uniform magnification and the magnification factor depends on the relationship between the focus-film and film-object distances. Multi-directional tomography provides images superior in quality to linear tomography because of more uniform blurring^{20,21}.

Spiral tomography

The Department of Radiology of the Institute of Dentistry, Turku University, Finland, and the Research and Development Department of the Sordex/Orion Corporation, Helsinki

carried out investigations between 1983 and 1989²¹ and used these to design the Scanora system. Spiral tomography can be performed with the Scanora (Soredex, Orion Corporation Ltd., Helsinki, Finland) which produces buccolingual cross-sectional tomograms. It was constructed as a multifunctional unit able to meet most dentomaxillofacial radiology needs.

Optimal tomographic images can be achieved by using spiral movements where the blurred shadows are placed at equal distances from each other in the partial attenuation zone and when the dose per turn is constant. A panoramic scout image is taken and the regions to be examined are defined. A specific computer program is used for each region of the maxilla or mandible. This system uses a fixed projection angle to produce a series of four images, 4 mm in thickness, centered 4 mm apart to include a 16-mm section of the jaw on one film²¹. It is possible to obtain four exposures per film using a field size of 7 cm × 10.2 cm. The Scanora has a constant magnification factor of 1.7²¹ (Figure 2) and the machine's slice thickness can be either 2 or 8 mm. When the canines are being examined, it is better to use a 2-mm cut in order to better demonstrate the anatomy in such a curved area. In a study of the reliability of spiral tomography, the inter-observer variations between the first and the second measurements were 1.67 mm and 1.42 mm, respectively; and the corresponding intra-observer variations were 1.07 mm and 0.86 mm. This variability was less than that seen when using hypocycloidal tomography because of the reduction in intra-observer variation and better image quality²⁰.

Scanora units give considerably lower radiation doses than does CT and their cost is approximately one-fifth of that of a CT machine^{21,22}. Nevertheless, when performing the multiple tomographic cuts needed for imaging an entire maxillary bone, the total dosage is higher than that for a

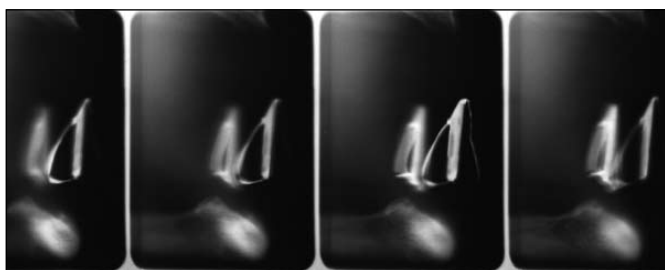


Figure 2 Spiral tomographs (Scanora) of anterior mandible and radiographic markers on plain film

reformatted CT scan examination²³. In complex situations where multiple implants are to be placed throughout the arch of the jaw, conventional X-ray tomography becomes impractical, as it is extremely time-consuming to produce a large number of cross-sectional tomograms⁷.

Computed tomography

Computed tomography was invented by Sir Godfrey Hounsfield and made known to the imaging world in 1972²⁴. The first CT scanners appeared in medical imaging departments during the mid-1970s and were so successful that they effectively 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.

Conventional (incremental) CT uses X-rays to produce sectional images as in conventional tomography. High-resolution images are achieved by scanning in an axial plane initially (maxilla: 20-30 axial slices; mandible: 30-35 axial slices, 1.5 mm thick and 1 mm apart with 0.5 mm overlapping), keeping the sections thin and making the scans contiguous or overlapping.

Use of spiral (helical) CT, which reduces both the radiation dose and investigation time, was proposed by Heiken *et al.*²⁵. The patient undergoes a translation (i.e. horizontal linear movement) simultaneously with the rotation of the X-ray source (spiral), allowing a continuous information stream during scanning. The slice thickness ranges from 0.4 to 1.0 mm without overlapping (Figure 3).

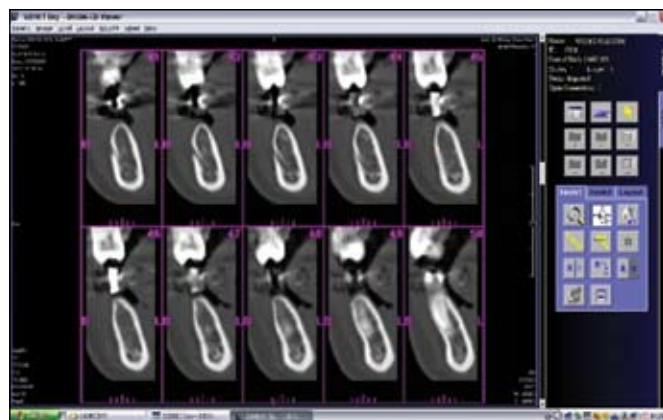


Figure 3 Reformatted computed tomographic images of posterior mandible with radiographic template

Conventional film is not used in spiral CT. Instead, radiation is detected by highly sensitive sensors and converted to digital data. These data can then be stored and manipulated using computer software to produce a gray scale image (0 for black and 255 for white) to form a matrix of picture elements (pixels). The software then allows multiple sections to be reformatted, the quality of which is dependent on the original scan section thickness and integers between successive sections. The cross-sectional reformatted images are based on the first axial scan demonstrating the full jaw contour. Reconstructed or reformatted images can be displayed on the monitor or transferred to film, photographic paper, or other materials for inclusion in a patient's record.

Computed tomographic scanning for dental implant surgery planning has been well described²⁶⁻²⁹. Computed tomographic scanning, which allows exact preoperative analysis of the available bone volume and helps to determine the appropriate position, angulation, number, and length of the planned implants, is highly recommended⁷. This modality also gives a high-density resolution, and the soft tissues can also be visualized to some degree. The reformatted CT images provide axial, panoramic, and cross-sectional images that are all cross-referenced to one another^{27,28}, allowing rapid correlation of the different views.

The most radiosensitive head and neck tissues, the corneas and the thyroid glands, may be avoided by scanning the patient in the axial plane⁷. Modern multi-slice CT scanners provide over 100 slices per rotation, so the scanning time is much reduced and the image quality much improved. It is also possible to display the CT number or Hounsfield units over selected regions of interest, thereby estimating the density of tissue at specific sites. This scale ranges from -1000 to +3000 and the relative densities are based on air (-1000), water (0), and dense bone/enamel/dental materials (+3000).

Computed tomography provides a much more accurate estimate of the position of the mandibular canal than does periapical and panoramic radiography and hypocycloidal tomography. For periapical radiographs, the corresponding figure was 53%, for conventional tomography 39%, and for panoramic radiography 17%³. The anterior mandibular buccal depression is more readily detected on CT scans than on panoramic radiographs³⁰. Computed tomographic

examinations with reformatted images are the only effective means of evaluating the bone volume present below the maxillary sinuses^{26,31,32}.

Computed tomographic images give anatomic structures, such as cortical bone, sharper borders than do spiral tomographic images. These apparently clear borders are the result of the calculated linear attenuation for a voxel, which is the weighted average of all tissues. This effect is called partial volume averaging but may result in unreliable depictions of bone thickness and affect the reliability of measurements.

Cone-beam computed tomography

In 2-dimensional imaging, each 2-dimensional pixel represents a 3-dimensional cube or voxel. Each pixel measures the total X-ray absorption throughout each voxel. This 2-dimensional limitation has been overcome by low-dosage cone-beam computed tomography (CBCT), which employs a cone-shaped X-ray beam rather than the flat fan-shaped beam used in conventional CT. The overall effective dosage is 0.035 to 0.10 mSv, which is equivalent to between two and eight panoramic radiographs. Individual voxels are much smaller than conventional CT voxels, resulting in greater resolution. Examples of such machines include NewTom DVT 9000 (Quantitative Radiology, Verona, Italy), i-CAT (Imaging Sciences International, Hatfield, USA), and 3D Accuitomo (J. Morita, Kyoto, Japan) [Figure 4].

A recent study comparing CBCT and the latest

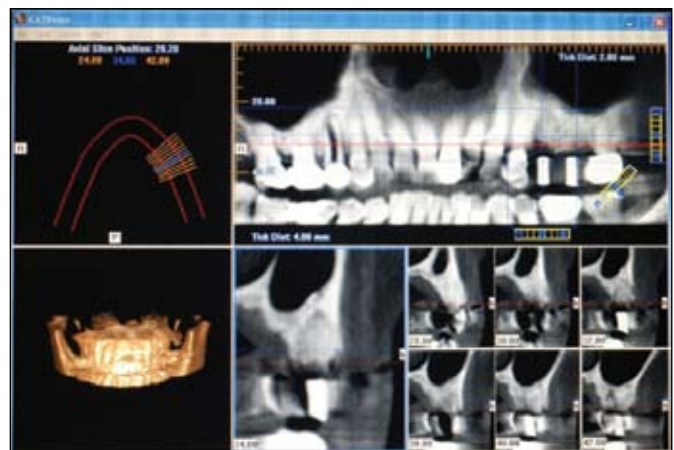


Figure 4 Tomographic cone-beam computed tomographic images analyzed with iCAT software

medical multi-slice CT-multidetector-row helical computer tomography (MDCT) showed that CBCT images of dental structures were superior to those produced by MDCT³³. The lower radiation dose and more user-friendly upright position used for scanning make CBCT the way forward for dental implant treatment planning.

Interactive computer-guided implantology

The evolution in hardware has been followed by refinements of software allowing 3-dimensional computer-assisted tomography-based implant planning. Interactive computer software programs now allow reformatted CT data to be analyzed on a personal computer when developing a treatment plan.

The 3-dimensional CT planning system is a reliable tool for the preoperative assessment of potential implant sites. A recently developed interactive 3-dimensional CT software program (SimPlant; Materialise, Leuven, Belgium) has made it possible to visualize the anatomical structures in a 3-dimensional mode on computer monitors for interactive implant placement. SimPlant uses raw data (DICOM files) from the CT scan to display reformatted CT images for the inspection of the bony anatomy of the alveolar ridges. Bone height and width can be easily measured from point to point. The planned implant length and diameter can therefore be determined. The angulation of the planned implant can be adjusted for optimal orientation with respect to the natural teeth and bony anatomy. The esthetic and biomechanical considerations (implant alignment) are made easier with 3-dimensional images³⁴. These interactive, reformatted cross-sectional images, used together with 3-dimensional reconstruction planning, give a better prognostic value than conventional reformatted cross-sectional CT planning for implant lengths¹⁴.

The CT scan data obtained from the SimPlant software can be used to produce sterolithographic models for 3-dimensional visualization for planning complex maxillofacial surgery. There are two techniques available for making sterolithographic models³⁵. The first technique applies laser technology in which a sterolithographic model is built up, layer by layer, with resin solution. A resin layer is solidified when its surface is struck with the laser. Another technique

uses a computer-aided milling machine. Surgical guides, and provisional and permanent restorations for implants, can all be fabricated using sterolithographic models³⁶ (Figures 5 and 6).

Magnetic resonance imaging

Magnetic resonance imaging was first introduced by Lauterbur³⁷. Magnetic fields and radiofrequencies, which are used by electromagnetic detectors to provide electronic images of body protons, are processed by a computer that generates them as digital images. There is no exposure to

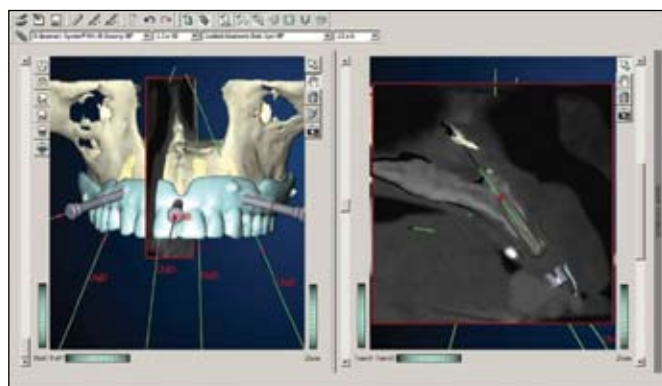


Figure 5 Interactive computer-guided implantology using NobelGuide (Nobel Biocare, Goteborg, Sweden) software system (courtesy of Dr Raymond Lop-Keung Chow)



Figure 6 Surgical template constructed using NobelGuide software system (courtesy of Dr Raymond Lop-Keung Chow)

radiation and soft tissues can be visualized when MRI is used. It can be used as a secondary imaging technique when primary imaging techniques such as complex tomography and CT scanning are not satisfactory³⁸.

The magnetic field strength used in MRI (up to 3.0 Tesla) is unlikely to cause tissue damage. It is believed that a much greater magnetic field strength could lead to marked heating of tissues but this potential heating problem has been overcome by the use of an advanced imaging excitation sequence. The presence of ferromagnetic (high magnetic susceptibility) metals can distort the magnetic field and compromise the images. Non-precious ferromagnetic alloys (cobalt-chromium) produce large image deformations, whereas precious alloys (Au, Ag, Ti, amalgam), which are mainly non-ferromagnetic, have no effect³⁹. Devge *et al.*⁴⁰ found that MRI images are not affected by implants of the Branemark system. On the other hand, MRI is contraindicated for patients with ferromagnetic metallic implants in their bodies because of the potential risks associated with movement or dislodgment of such objects⁴¹.

It has recently been proposed that MRI be used as an alternative technology for implant planning to avoid the radiation hazards associated with the use of CT⁴²⁻⁴⁴. However, MRI does not yield cortical bone images, so estimation of bone quality may be problematic⁴³. Taylor⁴⁵ criticized the use of MRI in dental implant treatment planning. He stated that MRI was not indicated when the location and volume of calcified tissues were the primary diagnostic concern. Unlike multi-plane reformatted CT images, cross-sectional MRI images are obtained using conventional reformatting due to the lack of software support for MRI data.

Summary

Dental implant therapy requires an accurate preoperative assessment of the patient's hard and soft tissues. Clinicians should understand the indications, applications, and limitations of different imaging techniques in order to obtain maximum information while keeping radiographic risks to a minimum. The use of CBCT with interactive planning software appears to meet the standard of care required for planning dental implant therapy.

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