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REVIEW ARTICLE

A comprehensive review of new innovations in dental implant imaging techniques

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Abstract

Background: Over the past three decades, dentistry has undergone considerable development in all of its branches. The need for more accurate diagnostic methods have become inevitable with these progresses. Advanced imaging methods such as computed tomography, cone beam computed tomography, magnetic resonance imaging have also found space in modern dentistry from the traditional intra-oral periapical X-rays. **Aim:** This paper is intended to explore recent developments in imaging technology and its applications in various dental disciplines. **Conclusion:** The three - dimensional visualization has made the complex cranio-facial structures more available for analysis and early and precise diagnosis of deep rooted lesions. **Clinical Significance:** Moving from analog to digital radiography has not only made the process easier and quicker, but has also enabled image storage, manipulation (brightness/contrast, cropping of images, etc.) and recovery.

Keywords: Cone-beam computed tomography, computed tomography, dental implants dental X-rays, intraoral X-rays

Introduction

Implant dentistry has grown in recent decades to become a prominent part of modern dental practice. Until the late 1980s, dental implant care was limited to edentulous patients only and was handled out by a team of specialist dentists at selected educational institutions or expert dental centers. Later with improvements in implant material, structure, and segments, the dental implants discovered their application to partially edentulous patients too.[1,2] Dental implants offer a solid alternative therapy for the recovery of patients who are partially or fully edentulous to receive different kinds of prostheses. When selecting a suitable implant site, it is important to consider other variables, i.e., bone strength, quantity, limiting structures, etc.

Implant efficacy depends on correct diagnosis and preparation of the procedure. Diagnostic imaging techniques help to create effective and accurate treatment plans for implant patients. Radiographic modalities help define region anatomic requirements for the positioning of implants. The selection of an accurate and comprehensive imaging system is the first and very basic step toward obtaining the required information along with the best dimensional accuracy. Until the late 1980s, traditional radiography was used as templates, for example, intraoral periapical (IOPA) radiography, cephalometric radiography, etc. With advancements in radiography, a lot of increasingly new cross-sectional radiographic imaging systems were introduced for embedded dental care, such as reformatted mechanized tomography. The American Oral and Maxillofacial Radiology Foundation in the year 2000 determined that standard cross-sectional tomography would be used for patients with implants.[3]

At present, a wide variety of imaging techniques is currently available, ranging from basic two-dimensional (2D) imaging techniques to three-dimensional (3D) imaging. Selection of imaging methods has become a challenge for implant treatment preparation.[3] Dental orthopantomograms (OPGs) have a magnification and distortion drawback and require a radiopaque marker to correct distortion. IOPA also has restrictions about the location of anatomical structures, i.e., maxillary sinuses and inferior alveolar canals. CT and CBCT do give 3D images, however, with the big downside of high-dose radiation. In this analysis, we will seek to integrate all of the implant imaging modalities their advantages and disadvantages.

Objectives of imaging

The main objectives of imaging implant sites are as follows:

- To assess the bone consistency and quantity that underlies it
- The detection of underlying bone pathologies

- To evaluate adjoining vital structures
- To estimate implant position, orientation, and prognosis
- There is also a need of evaluation for further bone grafting procedures.

The timing and type of imaging modality to be used depend on the integration of the phases referred to below: [3]

1. Step I (pre-surgical implant imaging): Imaging is conducted before implantation to assess the quantity and consistency of the bone and estimate the implant site with the vital structures, along with the designing of the orientation of the implants. Any preoperative information needed is evaluated
2. Step II (surgical and intraoperative implant imaging): Imaging in this process helps to assess the implant's optimum location and orientation along with correct alignment of the abutment and prosthesis fabrication
3. Step III (post-prosthetic implant imaging): Imaging in this process starts with implant placement and lasts for as long as the implant stays in the jaw. In this step, we assess the level of crestal bone around each implant along with assessing implant prognosis. This helps to determine improvements in bone volume and bone mineralization around the implant site.

The modalities of imaging can be analyzed under two headings: Conventional methods and advanced methods

1. Convention imaging includes:

a. IOPA
b. Bitewing radiographs
c. Occlusal radiographs
d. OPG
e. Digital radiography

2. Advanced techniques:

a. MRI
b. Computed tomography
c. Cone-beam computed tomography

Conventional imaging techniques have been commonly used in implant dentistry, but these techniques have their own drawback, i.e., it was possible to obtain only 2D images. To overcome these limitations, advanced diagnostic modalities emerged.

Magnetic Resonance Imaging

Lauterbur and Mansfield (noble price winners) discovered the magnetic resonance imaging (MRI). MRI produces accurate representations of organs and tissues within the body using a high uniform static magnetic field and radiowaves.[4] Due to its abundance of water and fat, the hydrogen nucleus (one single proton) is used for imaging purposes. The existence of high ferromagnetic metals (nickel and chromium, cobalt-chrome) can distort the magnetic field and degrade the photos while non-ferromagnetic alloys (titanium) do not produce image defects. Modern MRI machines use field strength magnets 0.5–2 Tesla (T). The magnet's power is directly proportional to its efficiency in detecting small lesions.[5] Most MRI devices are massive tube-shaped magnets that match the body's water molecules, which in effect generate signals by radiowave induction. The result is the creation of cross-sectional MRI.[6]

MRI images are not affected by BRANEMARK system implants according to Devge *et al.*[7] MRI helps differentiate inferior alveolar canal and neurovascular bundle from neighboring trabecular bone and determines the fat in the trabecular bone.[8,9] Radiation risk associated with CT is also lowered as compared. MRI has been contraindicated in patients who have been implanted with a ferromagnetic metallic implants in their body.[10] Due to the lack of support for MRI data tools, MRI images are collected using traditional reformatting.

Advantages of MRI

- MRI helps in differentiating cortical and cancellous bone
- Helps in obtaining information about implant length, angulation, and stability
- Vital structures are easily seen
- It is useful in soft-tissue imaging
- Flexible plane of acquisition is obtained with MRI without the requirement of reformatting.

Disadvantages of MRI

- MRI may show artifacts along with geometric distortion
- Area of signal loss may be seen from ferromagnetic material (e.g., dental amalgam)
- Artifacts are more common in post-prosthetic phase as implant produce extensive magnetic field distortion
- Strong static magnetic fields – As a result of ferromagnetic interactions, an object or device may be moved, rotated, dislodged, or accelerated toward the magnet.

Conventional Tomography

Term tomography is a combination of two words "Tomo" (Slice) and "Graph" (Picture) in the Greek language.[11] The motto used is called tomography, while the image generated in three dimensions is called tomogram.[11] Visualization of structures is achieved in this techniques by blurring the views above and below the section involved. Cross-sectional views are as small as 1 mm obtained from the tomographic slicing. Conventional tomography can be used either within one quadrant for single implant site or multiple implants where bone densities or volumetric analyses are not required. Diagnostic image quality depends on the type of movement of the tomography, segment thickness, and degree of magnification.

Many methods, such as spiral and linear, have been developed to reduce the blurring artifacts.

Linear Tomography

It is a comprehensible type of tomography, but the effect is standard streak artifacts known as "parasite line.[9]" Constant magnifications in tomographic images depend on the distance from the focus to the film to the target.

Advantages of linear tomography

- Least image distortion due to uniform magnification factor.

Disadvantages of linear tomography

- Blurring of area adjacent to implant site is seen in single dimension
- Metallic restorations may distort the desired image[12]
- In this technique, intensifying screen is used making it difficult to identify the anatomical structure and bone topography.

To overcome these limitations, multidirectional tomography became evident.

Spiral Tomography

In this technique, images are produced using spiral motion, and blurred shadows are kept at equal distances. It gives better contrast in 3D and a better resolution in space.[13] With a fixed projection angle, a projection of four images is created. Through view has a thickness of 4 mm, and all are 4 mm apart. In such views, the magnification is 10–30%. With more the magnification, higher is the image quality. This technique helps to determine the spatial relationship between specific anatomical structures and the location of the implants.[13,10]

Advantages

- Higher image quality
- For alveolus, high-quality complex motion tomography enables quantification of geometry
- For identifying critical structures, image enhancement can be done
- Spatial relationship between critical structures and implants can be identified.

Disadvantages of spiral tomography

- Operator sensitive
- Superimposing structures beyond the target field, causing image blurring
- Constant magnification is seen which varies from image to image
- Bone disease cannot be identified.

Transtomography or Sectional Tomography

Welander *et al.* defined this technique as a combination of translational motion and pendular beam and detector movement.[14]

Advantages

- This technique helps in obtaining immediate results suing computer program
- This technique can be used intraoperatively and measurements can be recorded on screen
- Less distortion is obtained than conventional tomography.

Computed Tomography

In the year 1972, British engineer Hounsfield discovered CT.[15] It was originally discovered for examining soft tissues, especially in brain. Nowadays, it is widely used in dentistry along with other branches of medicine, i.e., in temporomandibular joint imaging, for assessing maxillofacial regions. Cross-sectional tomographic images are digitally collected in this method, and image data are subsequently reformatted into the desired plane, i.e., axial or coronal as a means of post-imaging study.[10] Narrow X-ray beam is used. With the advances of CT, reformatted images are displayed at a section thickness of 1 pixel (0.25 mm) along with an in-plane resolution of 1 pixel through the scanning range (0.5–1.5 mm); therefore, the geometric resolution obtained is planar picture. All the structures shown have certain absolute densities and classification is performed based on quantitative density of the structure. By imposing, tissues that vary in density by <1% can be defined. Computed tomography can generate high-resolution, uniformly magnified, 3D images.

Advantages

1. In contrast to IOPA and OPG, CT can accurately locate nearby limiting structures
2. With CT, 3D reconstructions are possible.

Drawbacks

1. The key drawback CT is its high cost
2. Higher radiation dosage than OPG and linear tomography.

To conquer the drawbacks of conventional CT, multislice helical CT has been invented. It is more comfortable to the patient as it reduces patient motion and breath holding time during data acquisition, thus helps in obtaining a more rapid and extended coverage. Distortion in image is also less than conventional CT. It is almost 8 times faster, and therefore, slicing can be done up to 0.5 mm. It also helps in providing z-axis resolution of reconstructed data.

Tuned Aperture Computed Tomography (TACT)

TACT is another method as an alternative to film-based CT.[16] Image is produced in this technique by moving an object through a radiographic beam at distinct angles. It uses several small in close sequence fired radiographic tubes to create a single 3D image.[16] When firing, it can handle patient movement. TACT enhances the localization of bone disorder, anatomical structures, and implant site anomalies. This technique can be used to assess the amount of crest bones around implants.[17]

Dentascan Imaging

It is modern computer software that helps in the creation of maxilla and mandible computed tomography images in three planes, i.e., axial, panoramic, and oblique.

Advantages

1. Such 3D images help in the preparation of pre-surgical treatments
2. This system helps in calculating bone height and width along with diagnosing pathologies.

Disadvantages

1. Exposure to radiation
2. High cost
3. Magnification of image because the images produced is of not true size.[7]

Cone-Beam Tomography

CBCT is highly advanced imaging modality. It produces a 3D image that too with high resolution. The data collected in the image are reformatted using custom visualization tools. It is widely used in dentistry, for example, for assessing craniofacial lesions, for apical surgeries, in traumatology, etc. A cone-shaped ionizing radiation is directed through the center of the target field to an X-ray detector. CBCT allows the visualization of maxillofacial skeletons by 3D multiplanar. For any plane, the volume of the image can be recovered as well. CBCT is used in implant dentistry for quantitative and qualitative bone assessment and can be used for bone disease assessment at implant site.

Studies comparing CBCT and CT reliability have confirmed CBCTs dominance over the spiral CT, depending on the image quality.

According to the American Association of Oral and Maxillofacial Radiology, cross-sectional views should be used for planning dental implants. Therefore, with the CBCT thickness of the bone, bone width and height at the implant site can be measured with a high degree of accuracy.

- CBCT scanners are specifically designed to diagnose and plan for implant placements
- Multiple views of the area of interest are obtained in a single scan. This allows the dentist to perform minimally invasive surgery without lifting the flap, ultimately reducing surgery time, post-surgery pain, and swelling
- The master cast can be made before surgery using data stored on the software; a temporary restoration can be fabricated and placed immediately after surgery
- During the scanning process, radiographic markers may be inserted which indicate the exact location of the proposed implant. Stents help recognize radiographic landmarks that can be used to connect proposed implant position and angulations within the accessible alveolar bone
- Digital Imaging and Communications in Medicine data can be used to produce computer-generated surgical guides (stereolithographic models) [Figure 1] from the CBCT data
- The surgical guide [Figure 2] is used to help the surgeon place the implants in their best location. A specific surgical design that replicates the patient's alveolar structure can be developed from a model
- Template helps in determining position and orientation proposed implants.

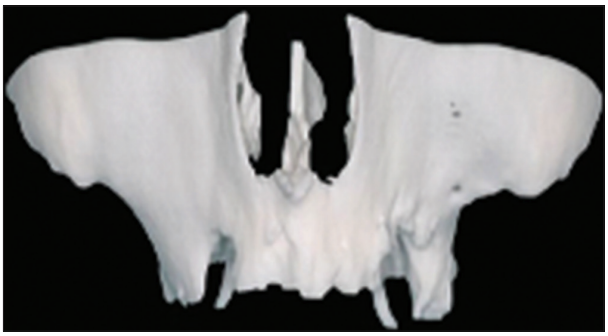

Figure 1: Stereolithographic model

Figure 2: Implant guide

Advantages of CBCT

1. Because of quick acquisition, the majority of the CBCT scan is completed in 30 s
2. CBCT has less image blur and magnification as opposed to periapical radiography and panoramic radiography
3. It is possible to specifically evaluate bone density, cortical plate thickness, trabecular pattern, and the relationship of any important structure such as the lower alveolar nerve with CBCT
4. High degree of accuracy in all 3D.

Disadvantages of CBCT[18]

1. Small degree of contrast
2. Restricted field of view
3. Due to small detector size, scanned volume is decreased
4. Gives less information about inner soft tissue
5. Increased noise from radiation scatter and artifacts
6. Radiation propagation
7. Prolonged scan time
8. Dynamic range of X-ray detectors.

Conclusion

Many imaging techniques are widely used in dentistry nowadays. Utilizing the correct and good imaging technique is in the hands of clinician. The choice of technique should be based on the appropriate dose, cost, and details. The ratio of the risk benefits should be measured. Although conventional radiography is of little importance in implant imaging, still panoramic radiographs are widely used due to less cost and easy access. MRI can be used to judge the positioning of vital structures. Best use of MRI is to detect the soft tissues. Since the emergence of CT it is possible to perform quantitative and qualitative bone analyzes for implant placement. Multi-slice helical CT is more beneficial than traditional CT, because it easily covers an expanded anatomical region with minimal patient movement. With the implementation of software used with CT or MRI, surgical prototype can be built. CBCT is the latest and safest technology used for dental implant imaging because it offers fast data collection with no exposure to radiation. CBCT has many other advantages over other techniques making it the most ideal choice for implant imaging.

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