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Abstract

Selecting an appropriate implant imaging technique has become a challenging task since the advent of advanced imaging modalities, and many of these are used for implant imaging. On imaging, the modality should not only consider the anatomy but should also provide dimensional accuracy. Many dentists use the conventional method, mostly orthopantomograph (OPG), in their routine practice of implant placement. However, because of the drawbacks associated with OPG, higher technologies, such as computed tomography (CT) and cone beam computed tomography (CBCT), are better accepted. These help improve image sharpness and reduce distortion. These techniques are not used widely due to the cost effect. Therefore, to decide on the type of imaging technique, all associated advantages and disadvantages should be considered, which will be broadly discussed in this review.

Keywords: implant, bone density, radiology, tomography, cone beam computed tomography

Introduction

To support a fixed dental prosthesis, metal posts are surgically implanted in the jaw. These metal posts are called dental implants (1). Other than occupying an edentulous site, an implant should also satisfy aesthetics while respecting the surrounding anatomical structures. While selecting an optimal implant site, certain factors should be considered, including identifying the detailed anatomy and determination of the boundaries of the bone, as well as its density and quality. Any underlying bony pathologies should also be determined (2).

Diagnostic imaging helps develop an appropriate and precise treatment plan for implant patients. Anatomic considerations of the area for implant placement should guide the appropriate radiological modalities (3). The selection of a type of imaging technique plays a major role in achieving the required information with the best dimensional accuracy. Radiographic techniques play an important role in pre-surgical, surgical, and post-prosthetic implant imaging.

Conventional radiographic techniques have been replaced by computed tomography (CT) and cone beam computed tomography (CBCT) to gain the maximum amount of information about the implant site. Therefore, to determine the best imaging modality for an intraoral implant placement, it is important to know the associated advantages and disadvantages, which shall be discussed henceforth in this article. All the pertinent published data from the journals and textbooks was reviewed from the year 1973 to 2013 to form this article. The keywords used were implants, imaging, implant radiology and implant dentistry.

Functions of Imaging

Imaging of the implant site is done to determine whether the patient can tolerate the surgical procedure, to identify underlying bony pathologies, undercuts and concavities, to assess bone density to know the approximation of vital anatomical structures and to estimate the dimensions, number, location, orientation,

and prognosis of the implant to be inserted. The need for additional bone treatments should be considered.

The objectives of diagnostic imaging depend on the amount and type of information required and the treatment period rendered. The timing and type of imaging modality to be used depends on the integration of the phases mentioned below (3):

PHASE I (Pre-surgical implant imaging)

To determine the bone quantity and quality and an approximation of the implant site with the critical structures, as well as to plan implant orientation, all necessary surgical and prosthetic information is obtained in this phase.

PHASE II (Surgical and intraoperative implant imaging)

Along with studying the optimal position and orientation of the implant, intraoperative implant imaging helps evaluate the healing and integration of surgery sites. The correct position of the abutment and prosthesis fabrication are ensured in this phase.

PHASE III (Post-prosthetic implant imaging)

This phase starts from the placement of the implant and lasts as long as the implant remains in the jaw. The radiographic sequence for phase III imaging is post-prosthetic imaging, followed by recall and maintenance imaging and an evaluation of alveolar bone change.

The various radiographic modalities used in different phases of treatment planning at various time intervals are given in Table 1.

Types of Imaging Modalities

Imaging examinations should be conducted with the aim of achieving the maximum benefit-to-risk ratio. The various useful imaging modalities for implant placements are (3):

Conventional techniques:

1. Periapical radiography
2. Bitewing radiography
3. Occlusal radiography
4. Cephalometric radiography
5. Panoramic radiography
6. Transtomography
7. Digital radiography

Although the crestal bone can be accessed using a bitewing radiograph, it is still of limited value in implant imaging because it has no other

associated advantages. Similarly, the maxillary and mandibular occlusal radiographs produce distorted images of the jaw; hence, they are not used in implant imaging.

Advanced techniques:

8. Magnetic resonance imaging
9. Conventional tomography
10. Computed tomography
11. Cone beam computed tomography

Periapical Radiography (PA)

Advantages:

1. In pre-surgical phase: PA provides a high-resolution planar image of a limited region of the jaws. It acts as a high-yield modality in ruling out dental disease in a localised area, as well as in the identification of critical structures.
2. In surgical phase: It is used to determine implant/ostetomy depth, position and orientation.
3. In post-prosthetic phase: high-quality images of the dental implant and the adjacent alveolar bone can be obtained.
4. The radiation source position depicts the precision and reproducibility of PA with a variation ranging as high as 20°. For this, a device with straight abutments of the Branemark system has been developed, which is fixed to a universal film holder to make the radiograph. Therefore, reproducible images can be taken for future comparisons.

Disadvantages:

1. In pre-surgical phase: Regarding distortion and magnification, a parallel technique eliminates distortion and limits magnification to less than 10%. It is of limited value in accessing the quantity and quality of bone, as well as in depicting the spatial relationship between the vital structures and the proposed implant site.
2. In post-prosthetic phase: The implant surface, where the central ray of the X-ray source lies, tangentially depicts the implant bone interface. Other regions of the implant interface are simply not depicted well by this modality.

Cephalometric Radiography

Advantages:

1. A cross-sectional image of the jaws can be demonstrated in the lateral incisor or in the canine regions by slightly rotating the

Table 1: Radiographic modalities for various treatment stages

Stage of treatment	Time (months)	Radiographic procedures
Treatment planning	-1	Periapical, orthopantograph, tomo, CT, ceph
Surgery (placement)	0	Periapical, orthopantograph, tomo, CT, ceph for correction of problems
Healing	0 to 3	Periapical, orthopantograph, tomo, CT, ceph for correction of problems
Remodelling	4 to 12	Periapical, orthopantograph
Maintenance (without problems)	13+	Periapical, orthopantograph (follow up approximately every 3 years)
Complications	Anytime	Periapical, orthopantograph, CT (as indicated)

Abbreviations: tomo = conventional tomography; CT = reformatted computed tomography; Ceph = lateral or lateral-oblique cephalometric radiography.

cephalometer. This view demonstrates the spatial relationship between occlusion and aesthetics and is more accurate for bone quantity determinations, which cannot be obtained in panoramic or periapical images. Implants often must be positioned in the anterior regions adjacent to the lingual plate.

2. It demonstrates the geometry of the alveolus in the mid-anterior region and the relationship of the lingual plate to the patient's skeletal anatomy.
3. Combining this technique with PA will result in obtaining the quantitative information of the implant site, as well as in helping to establish the relationship between the implant site and critical structures near the jaw.
4. It is useful for completely edentulous patients, as they can help evaluate the bone height using the cross-sectional image of the alveolus, crown-to-implant ratio, inclination of anterior teeth in prosthesis, skeletal arch interrelationship, soft tissue profile and resultant moment of forces.

Disadvantages:

1. The geometry of cephalometric imaging devices results in a 10% magnification of the image with a 60-inch focal object and a 6-inch object-to-film distance.
2. It fails to demonstrate the quality of the bone, where the central rays of the X-ray device are tangent to the alveolus.
3. Information is limited to the midline area. Any non-midline structure is superimposed on the contralateral side.
4. Accessing a cephalometric machine is

difficult.

5. This radiographic technique is operator technique-sensitive and, if improperly positioned, it will result in a distorted view.
6. Because lateral cephalometric radiographs use intensifying screens, resolution and sharpness are compromised in comparison to intraoral radiographic techniques.

Panoramic Radiography

Advantages:

1. In pre-surgical phase: The most used diagnostic modality; the image receptor may be a radiograph film, a digital storage phosphor plate or a digital charge-coupled device receptor.
2. Complete imaging of both jaws in one film.
3. Limited-angle linear tomography (zonography) is used as a means for patient positioning for making a cross-sectional image of the jaws in an attempt to modify the panoramic X-ray machine. The tomographic layer is approximately 5 mm thick, which helps determine the distance between the critical structures and the implant site, as well as the bone quantity at the site of implant placement.

Disadvantages:

1. Inherent magnification in the system: Panoramic radiography demonstrates vertical and horizontal magnification in the range of 15–22% (3). Least distortion is seen in the posterior maxilla on the radiograph. However, in a given

plane, horizontal distortion cannot be determined or measurements and images are completely unreliable (4,5). Alternatively, the vertical magnification factor of the image can be calculated by dividing the actual length of the object by the length measured on the radiographic image (6).

2. Patient positioning errors: With knowledge, most errors in patient positioning can be corrected.
3. The patient has to leave the surgical room and stand still for imaging purposes.
4. The resolution of the image is less compared to periapical images.
5. Zonography fails to identify disease at the implant site or access the differences in bone densities (7).

A technique for evaluating the panoramic radiograph for mandibular posterior implants, as well as for comparison with the clinical evaluation during surgery was developed by identifying the mental foramen and the posterior extent of the inferior alveolar canal. However, studies have demonstrated the mandibular foramen cannot be identified < 50% of the time on the radiograph film and, when visible, it may not be identified correctly (8).

Transtomography

Welander et al (9) described how direct digital transtomographic images could be obtained by combining the translational movement with the pendular movement of the beam and detector in advanced panoramic machines.

Advantages:

1. Images can be used for the same purposes as conventional tomography.
2. Immediate results can be obtained using a computer program intra-operatively (especially during blind surgical procedures) and measurements can be taken on the screen. This is achieved by positioning the patient using an individualised silicon key. This enables a limited distortion of the images compared to conventional tomographs and CT.

Digital Radiography

Advantages:

1. The resultant image can be modified in various ways, such as grayscale, brightness, contrast and inversion (10).

2. Computerised software programs (i.e. SimImplant) allow for the calibration of magnified images, thus ensuring accurate measurements (11).
3. Images are formed instantaneously during the surgical phase.

Disadvantages:

1. The size and thickness of the sensor and the position of the connecting cord makes positioning the sensor more difficult in sites, such as those adjacent to tori or the tapered arch form in the region of the canines.

Digital Subtraction Radiography

Subtraction is more accurate than PA in depicting changes, such as bone volume and bone mineralisation, as dark or light shades of grey. It can also depict buccal and lingual changes in the alveolar bone. However, this technique is of limited use in clinical practice because of the difficulty in obtaining reproducible PA (3).

Magnetic Resonance Imaging (MRI)

Gray, Redpath and Smith illustrated the scope of MRI used to obtain sectional information before an osseointegrated dental implant is placed in bone (13).

Advantages:

1. Details of available bone and delineation between cortical and cancellous bone can be clearly seen on MRI. This helps obtain information about maximum implant length, angulations and stability.
2. The vital structures are clearly seen as rendering good clinical results (3).
3. It is especially beneficial in the case of soft tissue imaging, when required (12). T1-weighted sequences are indicated, and an initial pilot scan with a low-resolution gradient echo sequence should be obtained in all three planes, as suggested by Gray (13). To set up high-resolution, fast spin echo axial slices, the sagittal plane must be used. Of all these slices, the slice showing markers is used to build a series of cross-sectional high-resolution images perpendicular to the region of interest. Using this, a scanning plane parallel to the area of interest is set up to obtain high-resolution images. To prevent the chances of foreshortening the measurement of the available bone, the plane should be set up in the line of

insertion of the dental implant.

4. MRI allows for a flexible plane of acquisition without the need for reformatting. It should be noted the slices should not intersect in the region of interest to make multiple site acquisitions.

Disadvantages:

1. MRI is subject to artefacts, geometric distortion, and areas of signal loss from ferromagnetic material, with the effects from dental amalgam being minor. Cortical bone gives no artefact on MRI and simply appears as an area of a low signal.
2. In the post-prosthetic phase, implants produce extensive magnetic field distortion and signal loss, resulting in minor artefacts. The MRI scans of patients with Branemark implants had only minor artefacts comparatively, but only as long as the fixation magnets were removed temporarily (3).

Conventional Tomography

An appropriate cross-sectional angulation is determined with the use of scout films, orientation laser light or wax bite registrations (14). However, manipulations can be done in the thickness, orientation and anatomic location of the image layer, which can also be predetermined. The closer and more perpendicular the long axis of the structure is to the relative path of tube travel, the more likely there will be image blurring and resolution.

Linear Tomography

Advantages:

1. Tomographic images have a uniform magnification factor that depends on the distance between the focus to film and film to object. As all structures lie at the same distance, these images are free from distortion.

Disadvantages:

1. Linear tomography causes blurring of the adjacent area in a single dimension with the use of a one-dimension motion.
2. It has a lack of adequate cross-referencing with standard lateral, frontal, and panoramic radiographs, due to which there is a need for a mental transformation before and during surgery.
3. Large metallic restorations in teeth lying

adjacent to the area of interest may distort the desired image.

4. It is difficult to identify anatomical structures and assess bone topography through this technique due to the use of an intensifying screen, causing a low resolution.

To avoid these disadvantages, the usability of multi-directional tomography has become evident (15,16).

Spiral Tomography

In this technique, blurred shadows are placed at equal distances from each other in the partial attenuation zone to obtain topographic images using spiral movements. The dose per turn is kept constant, and it uses a specific computer program for different areas of jaws, which are defined by a panoramic scout image. A series of four images are achieved by using a fixed projection angle, each 4mm thick and placed 4mm apart. Therefore, each film shows a 16mm section of the maxilla or mandible in total. Four exposures per film may be obtained using a field size of 7×10.2 cm. The diagnostic quality of the tomographic image is determined by the type of tomographic motion, the section thickness and the degree of magnification. For high-contrast anatomical objects with geometries that change over a short distance, such as the alveolus of the jaws, large-amplitude tube travel and 1mm sections are chosen.

Advantages:

1. Magnification varies from 10–30%, with a higher magnification generally producing higher-quality images.
2. For the alveolus, high-quality complex motion tomography enables quantification of the geometry, while considering magnification.
3. It helps to determine the spatial relationship between critical structures and the implant site. An evaluation of the implant site region with mental integration allows for appreciation of the quasi three-dimensional appearance of the alveolus. This is achieved by spacing tomographic sections every 1 or 2 mm apart. The bony quantity available for implant placement can be determined by compensating for magnification.
4. Critical structures can be identified by image enhancement.

Disadvantages:

1. Dense structures, such as teeth, exostoses, thick cortical plates, and dental materials/ restorations, are difficult to blur effectively when they are much denser than the structures depicted in the tomographic section (3).
2. Complex tomography is not of any importance in determining bone quality or identifying dental and bone disease.
3. Conventional tomograms will have a constant magnification that varies among different machines and can be as much as 40%.
4. This technique is an operator technique sensitive to the superimposition of structures outside the plane of focus, causing significant "blurring" of the image.

Computed Tomography (CT)

Hounsfield invented CT in 1972 (17), and the application of CT has been studied in imaging temporomandibular joint (TMJ) and dentoalveolar lesions, in assessing maxillofacial deformities and in evaluating the maxillofacial region pre- and post-operatively. Tangential and cross-sectional tomographic images of the proposed implant site are created by reformatting the image data as a means of a post-imaging analysis. With the advance of current-generation CT, the reformatted images are seen with 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 tissue differentiation and bone quality characterisation can be done by using the quantitative structure density of the image (18) (Table 2).

Advantages:

1. It helps in the identification of disease and proximity of vital structures at the site of implant placement so the proper orientation and position of the implant can be determined.

2. It helps determine the bone quantity and quality.

Disadvantages:

1. Conventional CT is associated with a high dose of radiation.

To overcome the limitations of conventional CT, multi-slice helical CT has been introduced recently.

Advantages of multi-slice helical CT:

1. It reduces patient motion and breath-holding time during data acquisition, leading to more rapid and extended anatomic coverage with decreased image noise, a reduced partial volume effect and a high-contrast image.
2. It is eight times faster at providing thick tissue slices while acquiring 0.5mm slices.
3. It provides an increased z-axis resolution of the reconstructed data.
4. Less waiting is required for tube cooling.

Cone Beam Volumetric Tomography (CBVT)

To overcome the disadvantages of conventional medical CT scanners, dental CT scanners have been developed recently to conduct a technique called CBCT. An X-ray source and detector are fixed to a rotating gantry to produce an image with the use of CBCT.

Advantages:

1. It minimises the cost of radiation detectors in conventional CT.
2. It provides a more rapid acquisition of the data set of the entire field of view (FOV).
3. It involves a shorter examination time, better image sharpness, reduced image distortion, and increased x-ray efficiency.

Disadvantages:

1. Image noise and low-contrast resolution due to the detection of scattered radiation are the biggest disadvantages of a large FOV.

Compact high-quality two-dimensional (2D) detector arrays and the refinement of approximate cone-beam algorithms have made the use of CBCT more acceptable.

CBCT Scanners

CBCT scanners (19) use a 2D extended digital array with a 3D x-ray beam and an area detector

Table 2: Bone Quality

Density	Hounsfield units (CT numbers)
D1	1250
D2	850–1250
D3	350–850
D4	150–350
D5	< 150

based on volumetric tomography. The image intensifier tube (IIT)–charge-coupled device in CBCT is well known for its use in maxillofacial imaging. Recently, the use of a flat panel imager (FPI) has been employed, which consists of a cesium iodide scintillator applied to a thin film transistor made of amorphous silicon. The various advantages associated with the use of FPI are images with lesser noise and an inherent detector configuration that reduces geometric distortions. CBCT imaging can be applied to planning implant placement (20–22) as well as to assessing any pathology for a surgical procedure (23–25), TMJ, and craniofacial fractures (26–28).

The CBCT software produces various real-time advanced image display techniques, including oblique planar reformation and curved planar reformation. To evaluate third molar impactions and TMJ, oblique planar reformation is used. Curved planar reformation helps to provide thin slice images of the dental arch to access the bone morphology through serial transplanar reformation, finding an association of critical structures with impacted third molars, to evaluate TMJ and pathological conditions affecting the maxilla and mandible. The number of voxels can be increased in the slide to thicken multi-planar volume reformations. This helps produce an unmagnified and undistorted “ray sum” image of the patient.

Software Applied to Oral Implantology

Computer software, when used with CT or MRI, has proven to be of great value in implant diagnosis and treatment planning (29). Using these software programs, near-original 3D images can be obtained along with the construction of surgical templates to transfer necessary information to the patient's mouth. Generally, this procedure is based on stereolithographic models (30–31). A 3D image is created by processing the CT data in the DICOM 3 format for accurate treatment planning in implant placement (32). With the use of various programs, such as Implametric®, SimPlant® (30–34), Nobel Guide® (35), med3D® (32), etc., surgical templates can be made for selective implant placement (33). Most programs show an axial cut and a panoramic cut with multiple buccolingual cuts (34). Essentially, computer-guided implant planning helps in visualising the anatomical structures in three spatial planes. Surgical navigation systems are currently able to offer greater security of critical structures to obtain improved results (31). These systems include RoboDent®, DenX IGI®, VISIT®, CADImplant®, LITORIM®, Virtual Implant®,

Vector Vision®, etc.

Guided image planning

Through guided planning, highly precise implant positioning can be obtained long with information regarding bone quantity for a minimally invasive surgery (36). Surgical guides help to transfer the diagnostic wax-up of the restoration into the actual implant planning (37).

Four kinds of templates can be used as tools with CT during implant planning, including vertical lead strip guides, circumference lead strip guides, gutta-percha guides or guides with a system of disks (38). All guides except vertical lead strip guides can be used as both a radiograph and as a surgical template. When a study was carried out using CT alone and CT with templates, better results were obtained in the latter (39). To achieve a more functional and aesthetic outcome, the template should not only be based on bone characteristics but also on the final shape of the tooth (40). With the help of templates, it is easier to place implants during a one-step surgery, especially in areas of anatomic limitations (41). Not only does it help in implant placement, but it also allows for the visualisation of the bone in each area to choose the ideal donor site for osseous grafts (42). In addition, 3D planning helps follow the critical anatomical structures along the implant trajectory when placing the transzygomatic implants (43). According to a study by Vrielink et al., (44), the accumulated success for transzygomatic implants was found to be 92% during a follow-up period of 15 months.

Guided Surgical Planning

For the success of surgical intervention, the exact position of the instruments must be known. CT or Remote neural Monitoring (RNM) images are used as maps to represent surgical instruments in relation to patient images. During surgery, this allows for the visualisation of the instrument position (45).

Computer-assisted surgery not only helps in implant placement, but it is also useful in arthroscopy of the TMJ, osteogenic distraction, biopsies, tumour treatment, deformities, and foreign body extirpation (45). Sensors are attached to the rotatory instruments, surgical template and patient's head cap. It is possible to see the real situation through data obtained from this navigation (29). The use of stereotactic systems in neurosurgery led to the development of systems based on ultrasounds and electromagnetic systems (46), as well as of optical navigation systems based on infrared light (45–47). The

accuracy of this system has been proven by various studies (47–49). Even though these systems are more vividly used, a new kind of sensor has been introduced, which is based on surface detection by a laser scanner.

The accuracy of computer-guided navigation is controlled by many factors, such as the transfer of data from planning to surgery, the surgeon's ability to interact with the system, not paying attention to the indications from the monitor and technical failures (50). A good control over these factors puts computer-guided navigation above manual implantation. The only disadvantage associated with this is the use of CT, leading to greater radiation exposure. To overcome this, the use of CBCT has been put forth by various studies (33,37,51). The various commercial systems available are RoboDent® (52), DenX IGI® (53), CADImplant®, VISIT®, LITORIM® (54), Vector Vision®, etc.

A good treatment plan will help reduce the total time, as well as surgical and post-operative complications, while improving the aesthetics and final functional outcome. Although the application of a navigation system has resulted in better implant placement, there is still a need for more clinical studies (55).

Conclusion

Conventional radiography is of little importance in implant imaging. Regardless, panoramic radiography remains the technique of choice due to its cost effect. To access the exact locations of vital structures, MRI can be of help, but it is subjected to artefacts, geometric distortion and areas of signal loss. It is best used when the delineation of soft tissue is also required. With the advent of CT, quantitative and qualitative analyses of bone can be conducted for implant placement. Multi-slice helical CT presents a greater advantage over conventional CT, as it rapidly covers an extended anatomic area with reduced patient motion. With the advent of software used with CT or MRI, a 3D model can be obtained and the construction of a surgical template is possible.

The recent technology used for dental implant imaging is CBCT, as it provides the rapid acquisition of data with little radiation exposure. It generates images replicating those used in daily clinical practice. Therefore, due to the greater advantages associated with CBCT over other techniques, it is the technique of choice for implant imaging.

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Conception and design, analysis and interpretation of the data: SG, NP

Drafting of the article, collection and assembly of data: SG

Final approval of the article: JS, NP

Provision of study materials or patient, statistical expertise: JS

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References

1. Abrahms JJ, Levine BP. Expanded applications of DentaScan. *Int J Periodontal Research Dent*. 1990;**10**:464–467.
2. Hatcher DC, Dial C, Mayorga C. Cone beam CT for pre-surgical assessment of implant sites. *J Calif Dent Assoc*. 2003;**31**(11):825–833.
3. Karjodkar FR. *Implant Radiology. Text book of dental and maxillofacial radiology*. 2nd ed. New Delhi (IND): Jaypee; 2011. p. 881–928.
4. Welander U, Tronje G, McDavid WD. *Theory of rotational panoramic radiography*. In: Langland OE, Langlais RP, McDavid WD, DelBalso AM, editors. *Panoramic radiology*. 2nd ed. Philadelphia (PA): Lea and Febiger; 1989. p. 38–75.
5. Truhlar RS, Morris HF, Ochi S. A review of panoramic radiography and its potential use in dentistry. *Implant Dent*. 1993;**2**:122–130.
6. Park JB. The evaluation of digital panoramic radiographs taken for implant dentistry in the daily practice. *Med Oral Patol Oral Cir Bucal*. 2010;**15**(4):e663–666. doi: 10.4317/medoral.15.e663.

7. Kircos LT, Misch CE. *Diagnostic Imaging and Techniques*. In: Misch CE, editor. Contemporary Implant Dentistry. 2nd ed. St Louis, Bosto, London, Philadelphia; 1999.
8. Yosue T, Brooks SL, the appearance of mental foramina on panoramic radiographs. Evaluation of patients. Oral Surg Oral Med Oral Pathol. 1989;**68(3)**:360–364.
9. Welander U, Li G, McDavid WD, Tronje G. Transtomography: a new tomographic scanning technique. *Dentomaxillofac Radiol*. 2004;**33(3)**:188–195. doi: <http://dx.doi.org/10.1259/dmfr/55001955>.
10. Kraut RA, Babbush CA. Radiographic evaluation of the implant candidate. In: Babbush CA, editor. Dental Implants, The Art And Science. 1st ed. Pennsylvania (PA): W.B. Saunders Publication; 2001. p. 35–36.
11. Marion LA, Amir AA, Virgine D, Laurent H. *Dental Implant Imaging: How CT Scan Became a Help to Surgery* [Internet]. [Place of publication unknown]: InTech; 2011 [Date of citation]. Available from: <http://cdn.intechopen.com/pdfs-wm/18423.pdf>.
12. Pevsner PH, Ondra S, Radcliff W, George E, McDonnell D, Furlow T. Magnetic resonance imaging of the lumbar spine. A comparison with computed tomography and myelography. *Acta Radiol Suppl*. 1986;**369**:706–707.
13. Gray CF, Redpath TW, Smith FW. Pre-surgical dental implant assessment by magnetic resonance imaging. *J Oral Implantol*. 1996;**22(2)**:147–153.
14. Shetty V, Benson BW. *Oraofacial implants*. In: White SC, Pharoah MJ, editors. Oral Radiology: Principles and Interpretation. 4th ed. St Louis (MO): Mosby; 2000. p. 623–635.
15. Grondahl K, Ekstubb A, Grondahl HG, Johnsson T. Reliability of hypocycloidal tomography for the evaluation of the distance from the alveolar crest to the mandibular canal. *Dentomaxillofac Radiol*. 1991;**20(4)**:200–204.
16. Tammissalo E, Hallikainen D, Kanerva H, Tammissalo T. Comprehensive oral X-ray diagnosis: Scanora multimodal radiography. A preliminary description. *Dentomaxillofac Radiol*. 1992;**21(1)**:9–15. doi: <http://dx.doi.org/10.1259/dmfr.21.1.1397455>.
17. Hounsfield GN. Computerized transverse axial scanning (tomography). 1. Description of system. *Br J Radiol*. 1973;**46(552)**:1016–1022. doi: <http://dx.doi.org/10.1259/0007-1285-46-552-1016>.
18. Salam AE, Askary E. *Diagnostic Considerations for Esthetic Implant Therapy. Fundamentals of Esthetic Implant Dentistry*. 1st ed. Australia (AUS): Blackwell; 2007. p. 13–78.
19. Scarfe WC, Farman AG, Sukovic P. Clinical Applications of Cone-Beam Computed Tomography in Dental Practice. *J Can Dent Assoc*. 2006;**72(1)**:75–80.
20. Sato S, Arai Y, Shinoda K, Ito K. Clinical application of a new cone-beam computerized tomography system to assess multiple two-dimensional images for the preoperative treatment planning of maxillary implants: case reports. *Quintessence Int*. 2004;**35(7)**:525–528.
21. Kobayashi K, Shimoda S, Nakagawa Y, Yamamoto A. Accuracy in measurement of distance using limited cone-beam computerized tomography. *Int J Oral Maxillofac Implants*. 2004;**19(2)**:228–231.
22. Hatcher DC, Dial C, Mayorga C. Cone beam CT for pre-surgical assessment of implant sites. *J Calif Dent Assoc*. 2003;**31(11)**:825–833.
23. Honda K, Matumoto K, Kashima M, Takano Y, Kawashima S, Arai Y. Single air contrast arthrography for temporomandibular joint disorder using limited cone beam computed tomography for dental use. *Dentomaxillofac Radiol*. 2004;**33(4)**:271–273. doi: <http://dx.doi.org/10.1259/dmfr/50972902>
24. Tsiklakis K, Syriopoulos K, Stamatakis HC. Radiographic examination of the temporomandibular joint using cone beam computed tomography. *Dentomaxillofac Radiol*. 2004;**33(4)**:196–201. doi: <http://dx.doi.org/10.1259/dmfr/27403192>.
25. Honda K, Arai Y, Kashima M, Takano Y, Sawada K, Ejima K, and other. Evaluation of the usefulness of the limited cone-beam CT (3DX) in the assessment of the thickness of the roof of the glenoid fossa of the temporomandibular joint. *Dentomaxillofac Radiol*. 2004;**33(6)**:391–395. doi: <http://dx.doi.org/10.1259/dmfr/54316470>.
26. Sukovic P. Cone beam computed tomography in craniofacial imaging. *Orthod Craniofac Res*. 2003;**6(Suppl 1)**:31–36. doi: 10.1034/j.1600-0544.2003.259.x.
27. Ziegler CM, Woertche R, Brief J, Hassfeld S. Clinical indications for digital volume tomography in oral and maxillofacial surgery. *Dentomaxillofac Radiol*. 2002;**31(2)**:126–130. doi: <http://dx.doi.org/10.1038/sj/dmfr/4600680>.
28. Heiland M, Schulze D, Rother U, Schmelzle R. Postoperative imaging of zygomaticomaxillary complex fractures using digital volume tomography. *J Oral Maxillofac Surg*. 2004;**62(11)**:1387–1391. doi: <http://dx.doi.org/10.1016/j.joms.2004.05.215>.
29. Hassfeld S, Mühling J. Computer assisted oral and maxillofacial surgery--a review and an assessment of technology. *Int J Oral Maxillofac Surg*. 2001;**30(1)**:2–13. doi: <http://dx.doi.org/10.1054/ijom.2000.0024>.
30. Ganz SD. Presurgical planning with CT-derived fabrication of surgical guides. *J Oral Maxillofac Surg*. 2005;**63(9 Suppl 2)**:59–71. doi: <http://dx.doi.org/10.1016/j.joms.2005.05.156>.
31. Ewers R, Schicho K, Undt G, Wanschitz F, Truppe M, Seemann R, et al. Basic research and 12 years of clinical experience in computer assisted navigation technology: a review. *Int J Oral Maxillofac Surg*. 2005;**34(1)**:1–8.

32. Engelke W, Capobianco M. Flapless sinus floor augmentation using endoscopy combined with CT scan-designed surgical templates: method and report of 6 consecutive cases. *Int J Oral Maxillofac Implants.* 2005;**20**(6):891–897.
33. Almog DM, LaMar J, LaMar FR, LaMar F. Cone beam computerized tomography-based dental imaging for implant planning and surgical guidance, Part 1: Single implant in the mandibular molar region. *J Oral Implantol.* 2006;**32**(2):77–81. doi: <http://dx.doi.org/10.1563/789.1>.
34. Parel SM, Triplett RG. Interactive imaging for implant planning, placement, and prosthesis construction. *J Oral Maxillofac Surg.* 2004;**62**(9 Suppl 2):41–47. doi: <http://dx.doi.org/10.1016/j.joms.2004.05.207>.
35. Rocci A, Martignoni M, Gottlow J. Immediate loading in the maxilla using flapless surgery, implants placed in predetermined positions, and prefabricated provisional restorations: a retrospective 3-year clinical study. *Clin Implant Dent Relat Res.* 2003;**5**(Suppl 1):29–36.
36. Fortin T, Bosson JL, Isidori M, Blanchet E. Effect of flapless surgery on pain experienced in implant placement using an image-guided system. *Int J Oral Maxillofac Implants.* 2006;**21**(2):298–304.
37. Fortin T, Bosson JL, Coudert JL, Isidori M. Reliability of preoperative planning of an image-guided system for oral implant placement based on 3-dimensional images: an in vivo study. *Int J Oral Maxillofac Implants.* 2003;**18**(6):886–893.
38. Almog DM, Torrado E, Moss ME, Meitner SW, LaMar F. Use of imaging guides in preimplant tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2002;**93**(4):483–487. doi: <http://dx.doi.org/10.1067/moe.2002.121389>.
39. Almog DM, Torrado E, Meitner SW. Fabrication of imaging and surgical guides for dental implants. *J Prosthet Dent.* 2001;**85**(5):504–508. doi: <http://dx.doi.org/10.1067/mps.2001.115388>.
40. Ito K, Gomi Y, Sato S, Arai Y, Shinoda K. Clinical application of a new compact CT system to assess 3-D images for the preoperative treatment planning of implants in the posterior mandible A case report. *Clin Oral Implants Res.* 2001;**12**(5):539–542. doi: [10.1034/j.1600-0501.2001.120516.x](http://dx.doi.org/10.1034/j.1600-0501.2001.120516.x).
41. Gaggl A, Schultes G, Santler G, Kärcher H. Treatment planning for sinus lift augmentations through use of 3-dimensional milled models derived from computed tomography scans: a report of 3 cases. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 1998;**86**(4):388–392. doi: [http://dx.doi.org/10.1016/S1079-2104\(98\)90361-4](http://dx.doi.org/10.1016/S1079-2104(98)90361-4).
42. González-García R, Naval-Gías L, Muñoz-Guerra MF, Sastre-Pérez J, Rodríguez-Campo FJ, Gil-Díez-Usandizaga JL. Preprosthetic and implantological surgery in patients with severe maxillary atrophy. *Med Oral Patol Oral Cir Bucal.* 2000;**10**(4):343–354.
43. Sorní M, Guarinos J, Peñarocha M. Implants in anatomical buttresses of the upper jaw. *Med Oral Patol Oral Cir Bucal.* 2005;**10**(2):163–168.
44. Vrielinck L, Politis C, Schepers S, Pauwels M, Naert I. Image-based planning and clinical validation of zygoma and pterygoid implant placement in patients with severe bone atrophy using customized drill guides. Preliminary results from a prospective clinical follow-up study. *Int J Oral Maxillofac Surg.* 2003;**32**(1):7–14. doi: <http://dx.doi.org/10.1054/ijom.2002.0337>.
45. Ewers R, Schicho K, Truppe M, Seemann R, Reichwein A, Figl M, et al. Computer-aided navigation in dental implantology: 7 years of clinical experience. *J Oral Maxillofac Surg.* 2004;**62**(3):329–334. doi: <http://dx.doi.org/10.1016/j.joms.2003.08.017>.
46. Nijmeh AD, Goodger NM, Hawkes D, Edwards PJ, McGurk M. Image-guided navigation in oral and maxillofacial surgery. *Br J Oral Maxillofac Surg.* 2005;**43**(4):294–302. doi: <http://dx.doi.org/10.1016/j.bjoms.2004.11.018>.
47. Siessegger M, Schneider BT, Mischkowski RA, Lazar F, Krug B, Klesper B, et al. Use of an image-guided navigation system in dental implant surgery in anatomically complex operation sites. *J Craniomaxillofac Surg.* 2001;**29**(5):276–281. doi: <http://dx.doi.org/10.1054/jcms.2001.0242>.
48. Wanschitz F, Birkfellner W, Watzinger F, Schopper C, Patruta S, Kainberger F, et al. Evaluation of accuracy of computer-aided intraoperative positioning of endosseous oral implants in the edentulous mandible. *Clin Oral Implants Res.* 2002;**13**(1):59–64. doi: [10.1034/j.1600-0501.2002.130107.x](http://dx.doi.org/10.1034/j.1600-0501.2002.130107.x).
49. Wagner A, Wanschitz F, Birkfellner W, Zauza K, Klug C, Schicho K, et al. Computer-aided placement of endosseous oral implants in patients after ablative tumour surgery: assessment of accuracy. *Clin Oral Implants Res.* 2003;**14**(3):340–348. doi: [10.1034/j.1600-0501.2003.110812.x](http://dx.doi.org/10.1034/j.1600-0501.2003.110812.x).
50. Brief J, Edinger D, Hassfeld S, Eggers G. Accuracy of image-guided implantology. *Clin Oral Implants Res.* 2005;**16**(4):495–501. doi: [10.1111/j.1600-0501.2005.01133.x](http://dx.doi.org/10.1111/j.1600-0501.2005.01133.x).
51. Meyer U, Wiesmann HP, Runte C, Fillies T, Meier N, Lueth T, et al. Evaluation of accuracy of insertion of dental implants and prosthetic treatment by computer-aided navigation in minipigs. *Br J Oral Maxillofac Surg.* 2003;**41**(2):102–108. doi: [http://dx.doi.org/10.1016/S0266-4356\(02\)00297-8](http://dx.doi.org/10.1016/S0266-4356(02)00297-8).
52. Casap N, Kreiner B, Wexler A, Kohavi D. Flapless approach for removal of bone graft fixing screws and placement of dental implants using computerized navigation: a technique and case report. *Int J Oral Maxillofac Implants.* 2006;**21**(2):314–319.
53. Van Steenberghe D, Naert I, Andersson M, Brajnovic I, Van Cleynenbreugel J, Suetens P. A custom template and definitive prosthesis allowing immediate implant loading in the maxilla: a clinical report. *Int J Oral Maxillofac Implants.* 2002;**17**(5):663–670.
54. Kramer FJ, Baethge C, Swennen G, Rosahl S. Navigated vs. conventional implant insertion for maxillary single tooth replacement. *Clin Oral Implants Res.* 2005;**16**(1):60–68. doi: [10.1111/j.1600-0501.2004.01058.x](http://dx.doi.org/10.1111/j.1600-0501.2004.01058.x).

55. Fortin T, Champleboux G, Bianchi S, Buatois H, Coudert JL. Precision of transfer of preoperative planning for oral implants based on cone-beam CT-scan images through a robotic drilling machine. *Clin Oral Implants Res.* 2002;**13**(6):651–656. doi: 10.1034/j.1600-0501.2002.130612.x.