Dental Imaging in Implant Treatment Planning

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One of the most important factors in determining implant success is proper treatment planning. Traditionally, conventional radiographic images (e.g., periapical and panoramic films) have been used to assist practitioners in planning implant treatment. Periapical radiographs present faithful images in terms of the size of the object examined as long as a parallel technique is used. Panoramic radiograph is an excellent tool for the overview of the maxillofacial area, including many of the vital structures, such as alveolar bones, maxillary sinus, inferior alveolar nerve (IAN), and temporomandibular joints. These conventional radiographics can also be used to identify pathologic abnormities. Conventional tomograms with cross-sectional views have expanded our ability to see 2-dimensional images to 3 dimensional levels. Although the earlier radiographic methods are commonly used, they have some inherent shortcomings, for example, a periapical film can only include about 3 teeth. Another limitation is the bending of the radiographic film to minimize patient discomfort, which may introduce some errors.[1] With regard to panoramic films, the lack of image sharpness and resolution, coupled with nonuniform distortion often leads to inaccurate interpretation and measurements.[2] The magnification of panoramic radiographs can be >30%, especially when patients are not in the optimal position.[3] Although offering an additional view, tomography can be difficult to interpret due to the wide depth of field in which objects anterior and posterior to the target blend into the image, creating an out-of-focus image. Furthermore, their magnification rate can be 40%.[4]

Objectives: *Proper implant treatment planning remains the first priority for implant success. Dental imaging is an important tool to accomplish this task. Traditional radiographs provide adequate information about proposed implant sites; however, limited film size, image distortion, magnification, and a 2-D view restrict their use in some cases. The purpose of this study is to provide an update about recent advancements in implant imaging to facilitate ideal implant treatment planning.*

Search Strategy: *A literature search was conducted using MEDLINE to identify studies related to this topic using the keywords of implant imaging, computed tomography (CT), cone beam CT (CBCT), and digital implant planning.*

Results: *Medical CT scan produce 3-dimensional replicas of anatomical areas with high resolution and accuracy. Although this type of imaging was introduced almost 20 years ago for implant planning, until recently it is widely used in most of the advanced procedures. CBCT is an advanced version of this technique. The advantages of CBCT are its specific design for the maxillofacial region, a reduced radiation exposure, cheaper, and excellent quality of images. Today, many companies are developing these cutting-edge machines and making it possible for dentists to use in their practices.*

Conclusions: *Coupled with converting software programs, CT/CBCT images may assist in selecting implant dimensions and predicting treatment outcomes. Understanding the up-to-date development of imaging aids could potentiate our ability in planning implant therapy. (Implant Dent 2010;19:288–298)*

Key Words: dental implants, computer tomogram, digital planning, CT scan, CBCT, cone beam CT

With the advent of technology, computed tomography (CT) has lead to a new era of implant imaging. CT offers all ranges of images such as cross-sectional, panoramic, or 3-dimensional views and each has high resolution as well as accuracy. Nowadays, CT scans are commonly used for implant treatment planning. Nevertheless, CT scans are not without their limitations/concerns and radiation exposure and cost are the major two. Furthermore, because of the size of the machine, CT scans are usually reserved for hospital settings.

Cone beam CT (CBCT) scanners, newer generation machines specifically designed for the maxillofacial region, have allowed for reduction in the

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radiation absorbed by the patient. It uses a single 360 degrees rotation around the maxillofacial region and a cone beam, in comparison, a spiral CT, which makes several rotations and uses a fan beam. When matched up next to the conventional CT, the lower cost, radiation exposure, and in-office feasibility of CBCT render it the ideal model for oral and maxillofacial radiology.

Another distinct advantage of CT/CBCT scan is the ability to plan implant therapy virtually with special 3-dimensional programs.[5] Some commonly used programs are Materialise's Simplant (Belgium), Nobel Biocare's Procera (Sweden), Implant Logic's VIP (USA), and iDent's Scan$_2$Guide (Israel). When those programs are applied, different diameters and length of implants can be "tried in" before the most optimal one is selected. Furthermore, the "placed" implant can be evaluated from several different viewpoints as well as 3-dimensional space. Moreover, once treatment planning is determined in the computer, it can be saved and applied to surgical sites by means of image-aided template production[6] or image-aided navigation.[7] The first aim of this review article is to summarize the current status of CT imaging, especially the advantages and the disadvantages of CT scan. The second aim is to discuss unique features of CBCT in comparison with CT scan. The third aim is the discussion on interactive 3-dimensional treatment planning for implant placement using software programs.

Computed Tomography

CT is a digital medical technique, which can generate 3-dimensional images of a patient's anatomy by reconstructing many axial slices. The newer generation of CT scans produces axial images perpendicular to the long axis of the patient by rotating a radiation source which emits fan-shaped beams 360 degrees around. The detectors capture x-rays, which transmit the subject and the data is processed by a computer. Because of the unique way, a CT scan acquires images and the reconstruction technology, CT imagines own high resolution and accuracy with minimum distortion and magnification.[8]

One of the prerequisites for proper implant treatment is to identify pertinent anatomical structures. Encroachment or damage of vital structures are unwanted complications and can be avoided. For example, in the posterior mandibular region, the IAN is an area of concern. CT scans can identify most inferior alveolar canals when multiple cross-sectional views are performed.[9] Although only few cases are reported in the literature, lingual plate perforations in the interforaminal area and their subsequent damage to branches of sublingual artery can be fatal.[10] Cross-sectional views obtained by CT scans can help clinicians to avoid these structures/problems. Tepper et al[11] have shown CT scans recognized at least 1 lingual perforating bone canal in the mandible. Therefore, this implies that the CT is a useful tool for planning implant procedures in the mandible to avoid complications.

CT scans can assist clinicians to select the proper implant diameter, length, and ideal position for placement. Images should be taken at one-to-one ratio without any distortion or magnification. CT scans have been shown to be very accurate with the magnification effect, the same for both the anterior and posterior area, from a range of 0% to 6% in horizontal as well as 0% to 4% in vertical dimension.[3] It is not surprising that implants placed based on CT results were more consistent with the planning treatment outcome, compared with panoramic views, which have a tendency to underestimate the implant length due to distortion and magnification effects. Pecker et al[4] compared the accuracy of 3 imagining methods: panoramic, conventional tomography, and CT for localizing the IAN. The various distances related to IAN were measured from different images and compared with direct measurements using a digital caliper. The result showed that the measurements obtained from CT were more consistent with direct measurements. The deviation from direct measurements was within 1 mm 97% of the time, compared with ~80% from panoramic views or conventional tomography.

Exposure Concerns From CT

The New England Journal of Medicine has recently raised the concern about the radiation doses acquired with the prevalent use of CT scans.[12] As a clinician, we must first understand the measurements of radiation so the comparison of a CT scan with different radiographic techniques can be made. This allows for better communication to relieve patient's concern. The ultimate goal is to obtain essential diagnostic information while adhere to the ALARA principle (as low as reasonably achievable). Radiation dose is represented in several ways for different purposes. The relevant units for CT scans are absorbed dose and effective dose.

The absorbed dose is defined as the energy absorbed in per unit of mass of any type of matter and is measured in grays (Gy). One gray equals to 1 joule of radiation energy absorbed in per kilogram. Specifically, the organ dose is derived from absorbed dose and means the distribution of dose in an organ of interest. It determines the quantity of dose received by that organ and thus the level of risk of that organ.

The effective dose, expressed in sieverts (Sv), is designed to estimate the overall harm of radiation in humans. In other words, it measures the equivalent whole-body dose. Because each organ is not sensitive to radiation equally, the tissue weighing factor (the radiosensitivity of different tissues for cancer formation or heritable effect) is considered before adding up all doses in different organs.

Radiation doses from any given CT study depend on a number of factors. The most important are the number of scans, the axial scan range, the scan pitch (the degree of overlap between adjacent CT slices), the tube voltage in the kilovolt peaks (kVp), the tube current and scanning time in milliampseconds (mAs), the size of the patient, and the specific design of the scanner being used.[12]

There are several ways to compare radiation exposure from different

Table 1. Comparison of Adsorbed Doses (mGy) Received in Various Radiosensitive Organs

Examinations	Skin Entrance	Salivary Gland	Thyroid Gland	Eye
Full mouth (18 films)[33]	37–45	2.3–5.7	0.4–0.7	0.4–1.9
Panographic film[33]	NA	3–11	0.05–0.5	0.05–0.1
Linear tomography (1 slice)[33]	0.3–0.4	0.025*	<0.01	<0.01
CT (mandible)[33]	46	31	3.7	1.7
CT (1 jaw)[34]	35–38	27–31	1.6	1.5
CBCT[20]	NA	5.7†	4.3	NA

*Weighed average from three main salivary glands.

†Right parotid gland only.

Table 2. Effective Dose and Associated Risk

Intraoral Radiography	Pano	Conventional Tomography	CT	CBCT
Effective dose during various examinations (uSv)[15,21]				
1–6 (1 PA film)	30	37–59 (1 site at mandible)	242–364 (mandible)	66–806
43–63 (full mouth)		74–134 (1 site at maxilla)	448–564 (maxilla)	
		264 (mandible)		
		477 (maxilla)		
Relative background radiation estimations (d)[16,35] (the annual environmental background is set at 4.4 uSv)				
7 (full mouth)	1	NA	33 (mandible)	12–26
			26 (maxilla)	
			38 (both jaw)	
Mortality risk ($\times 10^6$)[15,21] (according to ICRP1990)				
2–3 (full mouth)	1.5	2–3 (1 site at mandible)	12–18 (mandible)	2–59
		4–7 (1 site at maxilla)	22–28 (maxilla)	
		13 (mandible)		
		24 (maxilla)		

imaging sources and the easiest is to compare the absorbed doses. These were obtained from *in vitro* studies using anthropomorphic phantoms with thermoluminescent dosimeters fixed at appropriate locations, mimicking radiation exposures during examinations. Comparisons can also be made through annual natural background radiation or estimated annual risk of death.[13]

Most of the quantitative information regarding the risks of radiation-induced cancer comes from cohort studies of survivors of the atomic bombs dropped on Japan in 1945. The survivors have a significant increase in the risk of cancer. The cancer risks associated with CT exposure can be estimated by calculating the organ doses involved and applying organ-specific cancer incidence or mortality data derived in these studies.

Generally, CT produced considerably higher doses than conventional tomography and other image techniques. A study showed that doses absorbed by most organs were 3 to 10 times higher in CT scans when compared to conventional tomography and by single organs, up to 200 times higher.[14] A review article assesses the radiographic exposure from various methods and the associated risk to implant patients.[15] The effective dose of CT when 1 jaw is exposed ranges from 250 to 560 uSv, compared with 60 uSv when a full mouth periapical view is taken and 30 uSv when a panoramic film is acquired. When only 1 site is examined by a conventional tomograph, the effective dose is measured ~5 times less than CT scan. However, it is noted that when a whole maxilla or mandible is to be examined, the amount of radiation dose is similar between the 2 methods. The probability of death from CT scan reflects on those numbers. It is estimated that 12 to 28 people die from radiation-associated malignancies per million CT examinations.[15] The radiation of a jaw exposed to CT scan is equal to 26 to 33 days of background radiation, compared with 1 day of background radiation during panoramic examination.[16] Tables 1 and 2 summarize radiation doses from various modalities and associated risk.

Cone Beam CT

Because of higher radiation exposure, higher cost, huge footprint, and difficulty in accessibility associated with CT, a new type of CT, CBCT was developed.[17,18] CBCT was previously used in radiotherapy and have been applied in space, defense, and nuclear industry fields besides medicine. The primary difference between CBCT and CT is the shape of radiation beams and the mode of motion. As the name implies, CBCT generates cone-shaped beams and the imagines are acquired in 1 rotation by an imagine intensifier or flat panel detector, resulting in reasonably low levels of radiation dosage. In terms of patient's position, with CBCT machines, patients are seated or standing rather than supine. The theoretical resolution of CBCT is higher than CT. The voxel size, an indicator of resolution, can be as small as 0.1 mm for CBCT when compared

Table 3. Comparison Between CT and CBCT

	CBCT	CT
Differences		
Shape of radiation beam	Noncollimated, cone-shaped x-ray beam	Collimated, fan-shaped x-ray beam
Mode of movement	One 360 degrees rotation	Multiple spiral rotations
Size of the machine	Smaller (like a panoramic machine)	Larger (more than the size of a human)
Location	Dental office or imaging center	Hospital or imaging center
Cost	Less	More
Position of patient	Sitting or standing	Supine
Scan time	(10 to 40 s)	<10 s
Radiation exposure	Less	More
Image quality/image resolution	Voxel size can be as small as 0.1 mm Good for hard tissue but not discriminative for soft tissue	Voxel size is 0.5 mm at minimum High discriminate gray scale for both soft and hard tissue
Similarities		
Data acquisition	Axial slices stored in the form of 3.0 DICOM*	
Data processing	Compatible with software specified for dentistry Data can be reformatted into cross-sectional, panoramic, cephalometric and 3 dimensional view	
Implant therapy applications	Provide unique cross-sectional view and 3-D reconstructions Assist in diagnosis, treatment planning, including virtual implant placement, and the transfer of treatment plans into surgical sites	

DICOM indicates digital information communication for medicine.

to 0.5 mm for modern CT. In terms of economical aspect, CBCT is comparably more affordable for patients than CT and the estimate cost is about US$400 for both arches.[19] Table 3 summarizes comparisons between CT scan and CBCT.

Radiation Dose Reduction

One of the features of CBCT is the reduced radiation dose compared with CT. Recent studies on radiation doses suggested that generally patients received less radiation burden from CBCT than CT. The dose differences are detailed in Table 2. One aspect which should be addressed is the dose variation among different brands of CBCT. The NewTom 3G (QR, Verona, Italy) had fewer radiation exposure than iCAT (Imaging Sciences International, Hatfield, PA) by a factor of 2 and had 10 times less than CB Mercuray (Hitachi Medical Systems America, Twinsburg, OH) in similar conditions.[20] The primary reason for the difference is the higher electric current used (10 mA compared with 1.5 and 5.7) and longer exposure time (10 sec in contrast to 5–6 seconds) associated with CB Mercury. Generally, the size of the images dictates radiation doses. Large field of view is usually a synonym for more radiation exposure. Although different machine specifications and settings make direct comparison difficult, a study has showed that CBCT is a dose-sparing method by reducing effective doses up to 10 times compared with CT under similar condition.[21]

Validation of CBCT

CBCT is able to identify the IAN in clinical studies. One study[22] evaluated the ability of CBCT imagines to visualize IAN as well as alveolar crest in thirty patients without second premolar and all molars in the mandible. Seven observers examined 1 cross-sectional imagine around 1 mm posterior to mental foramen in each patient to evaluate whether the structures were clearly visible, probably visible, or invisible. The result showed that the visibility of anatomical structures examined as well as inter-examiner agreement was high with CBCT images. Another study compared the quality of CBCT imagines with panoramic images. Panoramic view reformatted from CBCT scan has shown better results in recognizing IAN than digital panoramic films when a 4-point subjective scale was used for evaluation.[23]

CT is considered the gold standard for its accuracy.[24] Comparison of linear accuracy of CBCT with CT have found CBCT is more accurate than CT.[25] The mean error was 4.7% (in dry mandible) and 2.3% (in sucrose solution) for CBCT, compared with 8.8% and 6.6% for CT, respectively. Chen compared ridge mapping, CBCT images and direct surgical access measurement in 16 patients with 25 implant planned sites.[26] Ridge mapping showed 89% to 94% of measurement deviations within 1 mm, while CBCT had 55% to 70% for the same deviation range. The authors questioned reliability of using CBCT in determining bone width. Nevertheless, it is noted that the slice thickness was 2 mm in this study, which may be too thick for the examination. On the basis of the earlier findings, CBCT can also

Table 4. Comparison of Some of Currently Available CBCT Devices

CBCT Devices	Company	FOV (cm)	Scan Time (s)	Tube Voltage (kV)	Tube Current (mA)	Reconstruction Time (min)	Voxel Size (mm^3)
AUGE series	Asahi Roentgen, Kyoto, Japan	5.1 × 5.1 7.9 × 7.1	17	60–95	2–12	N/A	0.1–0.15
Accuitomo	J Morita, Kyoto, Japan	4 × 3	18	60–80	1–10	<5	0.125
CBMercuRay	Hitachi, Kyoto, Japan	5.12 × 5.12 10.2 × 10.2 15 × 15 19 × 19	10	60–120	10	6	0.2–0.4
Galileos	Sirona, Charlotte, NC	12 × 15	14	85	5–7	4.5	0.15–0.3
Iluma	Imtec, Ardmore, OK	19 × 24	10−40	120	3.8	4	0.1–0.4
I-CAT	Imaging Sciences, Springfield, VA	20 × 25	5–25	120	1–3	<1	0.1–0.4
NewTom VG	QR, Verona, Italy	15 × 16	20	110	15	3	0.16–0.3
ProMax 3D	Planmeca, Roselle, IL	8 × 8	16–18	84	12	<3	0.16
Scanora 3D	Soredex, Finland	7.5 × 14.5	20	85	8	3	0.15–0.3

Table 5. Comparison of Some of Commonly Used Software Programs for Implant Planning

Software	Company	Features	Website
Simplant	Materialise, Belgium	Compatible with Stereolithography (SLA) technique	www.materialisedental.com
Procera	Nobel Biocare, Sweden	Compatible with SLA technique Dual-scan technique: the patient scanned with the guide and the guide itself alone	www.nobelbiocare.com
VIP	Implant Logic Cedarhurst, NY	Compatible with Five-axis milling technique Copu-Guide (Pilot and the Complete Compu-Guide)	www.implantlogic.com
$Scan_2Guide$	iDent, Israel	Compatible with SLA technique Have license to make guides in the United States Dual-scan technique	www.ident-surgical.com
InVivoDental	Anatomage, CA	Volumetric superimposition function 3D Stitching Plugin Create-Model (compatible with SLA)	www.anatomage.com
Facilitate	AstraTech, Sweden	Based on the SimPlant software	www.astratech.nl
EasyGuide	Keystone Dental, MI	X marker: allow for surgical guide manufacturing process	www.keystonedental.com
Dolphin3D	Patterson Dental, St. Paul, MN	Volume-to-volume superimposition 3D nerve marking	www.dolphinimaging.com
AccuDental	Medical Modeling, CO	Compatible with SLA technique	www.medicalmodeling.com

identify some critical anatomical structures relevant to implant placement and provide accurate images for implant planning.

With the popularity of CBCT, more and more companies are developing new models to improve the properties of images. Table 4 features some of currently available CBCT machines in the market.

Interactive Implant Treatment Planning

The philosophy of prosthodontic-driven implant placement has revolutionized how implant dentistry is practiced.[27] The idea of placing implants based upon available bone has long gone. In this new era, functional, esthetic, and prosthetic applicability are all incorporated into overall implant diagnosis and treatment planning. The prosthetic designs dictate the position of dental implants. Model-based treatment planning with the assistance of CT images has been developed to fulfill this purpose.[4] After a diagnostic cast and a preplanned wax-up, diagnostic templates are fabricated or modified from existing dentures.[28] The implant position as well as direction is determined based on final restoration position using radiopaque material, such as gutta percha[29] or metal pins[19] to mark the spots. Images are then evaluated for available bone height, width and related vital anatomical structures. According to this information, changes can be made to accommodate final implant position. A second guide can be fabricated manually based on the modification or this stent can be used as a surgical guide during the operation. This approach has shown to be a successful technique. In a cadaver study, the mean angular error was 1.3 degrees (max: 4 degrees) and the mean horizontal error was 0.4 mm (max: 1.5 mm).[30] A clinical study evaluated the transfer error of a surgical template by comparing the proposed and actual direction. The deviation is on average 5 degrees, with a range of 0.5 degrees to 14.5 degrees.[31]

With the aid of interactive software, another approach for the transfer of implant planning to the surgical site is to use computer-aided design/computer-aided manufacturing technique. Many software programs are currently available (Table 5). These

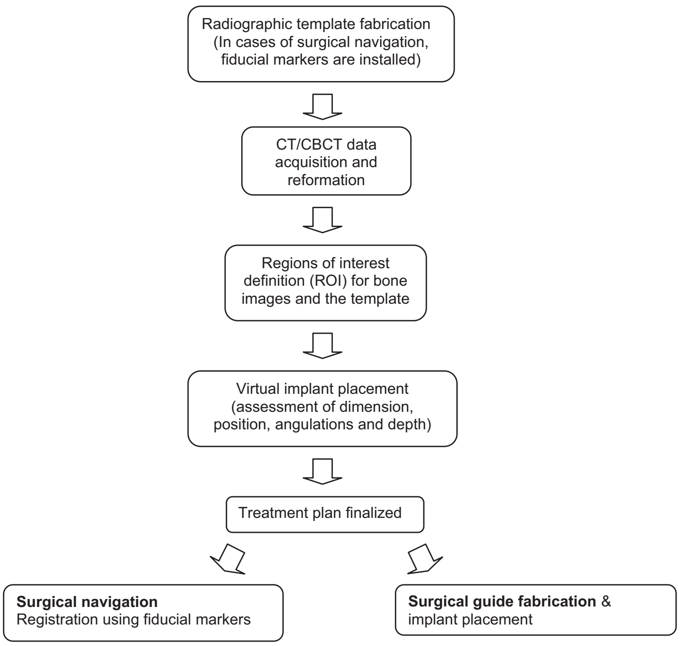

Fig. 1. Procedures of software-aid implant therapy.

programs enable a clinician to transfer CT/CBCT findings into surgical area.

Using one of these programs, the implant treatment team has the ability to "try in" different diameters and length of implants and selects the ideal one. Furthermore, the placed implant can be evaluated from several different viewpoints as well as from 3-dimensional view. It can also be rotated and tilted on any axis to adjust its position. For multiple implant placements, the parallel relationship to simplify prosthetic reconstruction can be ascertained. Moreover, once treatment planning is determined in the computer, it can be saved and applied to surgical sites by means of image-aided template production[6] or image-aided navigation.[7] The primary interest in the literature is the accuracy of transferring treatment plan into surgical field. CT based implant planning and its transfer to the surgical field via a surgical guide has resulted ~1 mm of mean linear deviation and 3degrees mean angulation difference. Although computer-aided-implant placement is a promising technique, the unexpected high linear deviation which sometimes reaches 4 mm and angulation deviation 17 degrees[32] can be a major concern. Hence, more research is needed before this approach can be widely used. Figure 1 illustrates how CT/CBCT can assist in implant planning.

CONCLUSIONS

CT assists clinicians in identifying bone volume, jaw tomography important anatomical, and landmarks. However, because of its higher radiation dose and cost, CBCT was introduced to overcome these shortfalls. With images acquired from CBCT and the assistance of software programs, clinicians may now place implants in the ideal position while avoiding vital structures so they can fulfill esthetic, functional, and biologic demands.

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The author(s) claim to have no financial interest in any company or any of the products mentioned in this article.

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REFERENCES

1. Gher ME, Richardson AC. The accuracy of dental radiographic techniques used for evaluation of implant fixture placement. *Int J Periodontics Restorative Dent*. 1995;15:268-283.
2. Wyatt CC, Pharoah MJ. Imaging techniques and image interpretation for dental implant treatment. *Int J Prosthodont*. 1998;11:442-452.
3. Reddy MS, Mayfield-Donahoo T, Vanderven FJ, et al. A comparison of the diagnostic advantages of panoramic radiography and computed tomography scanning for placement of root form dental implants. *Clin Oral Implants Res*. 1994;5: 229-238.
4. Peker I, Alkurt MT, Michcioglu T. The use of 3 different imaging methods for the localization of the mandibular canal in dental implant planning. *Int J Oral Maxillofac Implants*. 2008;23:463-470.
5. Jeffcoat M, Jeffcoat RL, Reddy MS, et al. Planning interactive implant treatment with 3-D computed tomography. *J Am Dent Assoc*. 1991;122:40-44.
6. Verstreken K, Van Cleynenbreugel J, Marchal G, et al. Computer-assisted planning of oral implant surgery: A three-dimensional approach. *Int J Oral Maxillofac Implants*. 1996;11:806-810.
7. Siessegger M, Schneider BT, Mischkowski RA, et al. Use of an image-guided navigation system in dental implant surgery in anatomically complex operation sites. *J Craniomaxillofac Surg*. 2001;29: 276-281.
8. Kalender WA. *Computed Tomography-Fundamentals, System Technology, Image Quality and Applications.* Weinheim, Germany: WUey-VCH Verlag GmbH & Co; 2000.
9. Todd AD, Gher ME, Quintero G, et al. Interpretation of linear and computed tomograms in the assessment of implant recipient sites. *J Periodontol*. 1993;64: 1243-1249.
10. Mordenfeld A, Andersson L, Bergstrom B. Hemorrhage in the floor of the mouth during implant placement in the edentulous mandible: A case report. *Int J Oral Maxillofac Implants*. 1997;12:558-561.
11. Tepper G, Hofschneider UB, Gahleitner A, et al. Computed tomographic diagnosis and localization of bone canals in the mandibular interforaminal region for prevention of bleeding complications during implant surgery. *Int J Oral Maxillofac Implants*. 2001;16:68-72.
12. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. *N Engl J Med*. 2007;357: 2277-2284.
13. Harris D, Buser D, Dula K, et al. E.A.O. guidelines fo the use of diagnostic imaging in implant dentistry. A consensus workshop organized by the European Association for Osseointegration in Trinity College Dublin. *Clin Oral Implants Res*. 2002;13:566-570.

14. Ekestubbe A, Thilander A, Grondahl HG. Absorbed doses and energy imparted from tomography for dental implant installation. Spiral tomography using the Scanora technique compared with hypocycloidal tomography. *Dentomaxillofac Radiol*. 1992;21:65-69.

15. Dula K, Mini R, van der Stelt PF, et al. The radiographic assessment of implant patients: Decision-making criteria. *Int J Oral Maxillofac Implants*. 2001;16:80-89.

16. Guerrero ME, Jacobs R, Loubele M, et al. State-of-the-art on cone beam CT imaging for preoperative planning of implant placement. *Clin Oral Investig*. 2006;10:1-7.

17. Arai Y, Tammisalo E, Iwai K, et al. Development of a compact computed tomographic apparatus for dental use. *Dentomaxillofac Radiol*. 1999;28:245-248.

18. Mozzo P, Procacci C, Tacconi A, et al. A new volumetric CT machine for dental imaging based on the cone-beam technique: Preliminary results. *Eur Radiol*. 1998;8:1558-1564.

19. Peck JN, Conte GJ. Radiologic techniques using CBCT and 3-D treatment planning for implant placement. *J Calif Dent Assoc.* 2008;36:287-290.

20. Ludlow JB, Davies-Ludlow LE, Brooks SL, et al. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. *Dentomaxillofac Radiol*. 2006;35:219-226.

21. Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2008;106:106-114.

22. Lofthag-Hansen S, Grondahl K, Ekestubbe A. Cone-beam CT for preoperative implant planning in the posterior mandible: Visibility of anatomic landmarks. *Clin Implant Dent Relat Res*. 2009;11:246-255.

23. Angelopoulos C, Thomas S, Hechler S, et al. Comparison between digital panoramic radiography and cone-beam computed tomography for the identification of the mandibular canal as part of presurgical dental implant assessment. *J Oral Maxillofac Surg*. 2008;66:2130-2135.

24. Loubele M, Maes F, Schutyser F, et al. Assessment of bone segmentation quality of cone-beam CT versus multislice spiral CT: A pilot study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2006;102:225-234.

25. Suomalainen A, Vehmas T, Kortesniemi M, et al. Accuracy of linear measurements using dental cone beam and conventional multislice computed tomography. *Dentomaxillofac Radiol*. 2008;37:10-17.

26. Chen L-C, Lundgren T, Hallstrom H, et al. Comparison of different methods of assessing alveolar ridge dimensions prior to dental implant placement. *J Periodontol*. 2008;79:401-405.

27. Becker CM, Kaiser DA. Surgical guide for dental implant placement. *J Prosthet Dent*. 2000;83:248-251.

28. Israelson H, Plemons JM, Watkins P, et al. Barium-coated surgical stents and computer-assisted tomography in the preoperative assessment of dental implant patients. *Int J Periodontics Restorative Dent*. 1992;12:52-61.

29. Klein M, Cranin AN, Sirakian A. A computerized tomography (CT) scan appliance for optimal presurgical and preprosthetic planning of the implant patient. *Pract Periodontics Aesthet Dent*. 1993;5:33-39, quiz 39.

30. Modica F, Fava C, Benech A, et al. Radiologic-prosthetic planning of the surgical phase of the treatment of edentulism by osseointegrated implants: An in vitro study. *J Prosthet Dent*. 1991;65:541-546.

31. Naitoh M, Ariji E, Okumura S, et al. Can implants be correctly angulated based on surgical templates used for osseointegrated dental implants? *Clin Oral Implants Res*. 2000;11:409-414.

32. Vercruyssen M, Jacobs R, Van Assche N, et al. The use of CT scan based planning for oral rehabilitation by means of implants and its transfer to the surgical field: A critical review on accuracy. *J Oral Rehabil*. 2008;35:454-474.

33. Clark DE, Danforth RA, Barnes RW, et al. Radiation absorbed from dental implant radiography: A comparison of linear tomography, CT scan, and panoramic and intra-oral techniques. *J Oral Implantol.* 1990;16:156-164.

34. Ekestubbe A, Thilander A, Gröndahl K, et al. Absorbed doses from computed tomography for dental implant surgery: Comparison with conventional tomography. *Dentomaxillofac Radiol.* 1993;22:13-17.

35. White SC. 1992 assessment of radiation risk from dental radiography. *Dentomaxillofac Radiol.* 1992;21:118-126.

ID Abstract Translations

GERMAN / DEUTSCH

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Bildgebung in der Zahnmedizin bei der Planung von Implantierungsbehandlungen

ZUSAMMENFASSUNG: Zielsetzungen: Für einen guten Erfolg bei der Implantierung bleibt immer noch die gute Planung und Vorbereitung einer Implantierungsbehandlung das maßgebliche Element. Hierbei spielt die zahnmedizinische Bildgebung eine große Rolle. Die traditionellen Röntgenaufnahmen bieten eine gute Informationsbasis über die zur Implantierung vorgesehenen Bereiche. Allerdings schränken die begrenzte Filmgröße, die Bildverzerrung, die Vergrößerung sowie eine ausschließliche 2-D-Betrachtung deren Verwendung in einigen Fällen ein. Die vorliegende Arbeit zielt daher darauf ab, eine Aktualisierung zu den neuesten Entwicklungen auf dem Gebiet der Implantierungsbildgebung darzulegen, um eine ideale Planung der Implantierungsbehandlung zu erleichtern. ***Suchstrategie:*** Über MEDLINE wurde eine Literatursuche durchgeführt, um mit diesem Themenkomplex in Verbindung stehende Studien zu finden. Dabei wurden als Stichworte "Implantierungsbildgebung", "Computertomographie (CT)", "Kegelstrahl-Computertomographie (CBCT)" sowie "digitale Implantierungsplanung" verwendet. ***Ergebnisse:*** Durch die medizinischen CT-Scans entstanden 3-dimensionale Kopien der anatomischen Bereiche mit hoher Auflösung und Genauigkeit. Obwohl diese Art der Bildgebung bereits vor beinahe 20 Jahren zur Implantierungsplanung eingeführt wurde, wurde sie erst vor kurzem für die meisten fortschrittlichen

Abläufe eingesetzt. CBCT stellt eine fortschrittliche Abart dieser Technologie dar. Die Vorteile des CBCT liegen in seinem spezifischen Design für den Gesichts-Kiefer-Bereich, in einer verringerten Strahlenbelastung, sowie in den geringeren Kosten und der hervorragenden Qualität der Bilder. Heutzutage entwickeln viele Firmen diese innovativen Maschinen und machen diese damit zur Nutzung in den Praxen der Zahnärzte verfügbar. ***Schlussfolgerungen:*** In Verbindung mit Konvertierungssoftware, können CT/CBCT-Bilder eine gute Hilfestellung bei der Auswahl der Implantatabmessungen und bei der Vorhersage der Behandlungsergebnisse darstellen. Ein Verständnis der heutigen Entwicklung der Bildgebenden Hilfen könnte unsere Möglichkeiten der Planung einer Implantierungstherapie um einiges verbessern.

SCHLÜSSELWÖRTER: Zahnimplantate, Computertomograph, digitale Planung, CT-Scan, CBCT, Kegelstrahl-CT

SPANISH / ESPAÑOL

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Imágenes dentales en el planeamiento del tratamiento con implantes

ABSTRACTO: Objetivos: La planificación correcta del tratamiento con implantes sigue siendo la primera prioridad para lograr el éxito del implante. Las imágenes dentales son una herramienta importante para cumplir esta tarea. Las radiografías tradicionales proporcionan información adecuada sobre los lugares propuestos de los implantes; sin embargo, el tamaño limitado de la película, la distorsión de la imagen, magnificación y la perspectiva bidimensional restringen su uso en algunos casos. El propósito de este trabajo es ofrecer una actualización sobre avances recientes en las imágenes de los implantes para facilitar el planeamiento ideal del tratamiento con implantes. ***Estrategia de la búsqueda:*** Se realizó una búsqueda en la literatura usando MEDLINE para identificar estudios relacionados con este tema usando las palabras claves imágenes de implantes, tomografía computada (TC), tomografía computada Cone Beam (CBCT por sus siglas en inglés) y planeamiento digital de implantes. ***Resultados:*** Una tomografía computada médica produce réplicas tridimensionales de zonas anatómicas con alta precisión y resolución. A pesar de que este tipo de imágenes fueron introducidas casi hace 20 años para la planificación de implantes, hasta hace poco se usó ampliamente en la mayoría de los procedimientos avanzados. La CBCT es una versión avanzada de esta técnica. Las ventajas de la CBCT son su diseño específico para la región maxilofacial, menos contacto con la radiación, menos costo y una excelente calidad de las imágenes. Hoy muchas compañías fabrican estas máquinas de avanzada y hacen que sea posible para los dentistas usarlas en sus prácticas. ***Conclusiones:*** Junto a programas de conversión, las imágenes de TC/CBCT podrían ayudar a seleccionar las dimensiones del implante y pronosticar los resultados del tratamiento. Entender el desarrollo actualizado de la creación de las imágenes podría mejorar nuestra capacidad en el planeamiento de la terapia con implantes.

PALABRAS CLAVES: Implantes dentales, tomograma computado, planeamiento digital, tomografía computada, CBCT, tomografía computada Cone Beam

PORTUGUESE / PORTUGUÊS

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Imageamento Dentário em Planejamento de Tratamento de Implante

RESUMO: Objetivos: O planejamento adequado de tratamento de implante permanece a primeira prioridade para o sucesso do implante. O imageamento dentário é uma ferramenta importante para realizar esta tarefa. As radiografias tradicionais fornecem informações adequadas sobre locais de implante propostos; contudo, o tamanho limitado do filme, distorção da imagem, ampliação e visão em 2-D restringem seu uso em alguns casos. O objetivo deste artigo é fornecer uma atualização sobre avanços recentes em imageamento de implante para facilitar o planejamento ideal de tratamento de implante. ***Estratégia de Pesquisa:*** Uma pesquisa na literatura foi conduzida usando MEDLINE para identificar estudos relacionados a este tópico usando as palavras-chave de imageamento de implante, tomografia computadorizada (CT), tomografia computadorizada por feixes cônicos (CBCT) e planejamento digital de implante. ***Resultados:*** O mapeamento médico por tomografia computadorizada produz réplicas tridimensionais de áreas anatômicas com alta resolução e precisão. Embora este tipo de imageamento tenha sido introduzido há quase 20 anos para planejamento de implante, até recentemente ele foi usado na maior parte dos procedimentos avançados. A CBCT é uma versão avançada desta técnica. As vantagens da CBCT são seu design específico para a região maxilofacial, uma reduzida exposição à radiação, preço menor e excelente qualidade das imagens. Hoje, muitas empresas estão desenvolvendo essas máquinas de ponta e tornando possível aos dentistas usá-las em suas clínicas. ***Conclusões:*** Acopladas a programas de conversão, as imagens de CT/CBCT podem assistir na seleção de dimensões de implante e previsão de resultados de tratamento. Entender o desenvolvimento atual de meios de imageamento poderia potencializar nossa capacidade de planejar a terapia de implante.

PALAVRAS-CHAVE: Implantes dentários, tomograma computadorizado, planejamento digital, mapeamento por tomografia computadorizada, CBCT, tomografia computadorizada por feixes cônicos

RUSSIAN / РУССКИЙ

АВТОРЫ: Hsun-Liang Chan, доктор хирургической стоматологии, Kelly Misch, доктор хирургической стоматологии, магистр естественных наук, Hom-Lay Wang, доктор хирургической стоматологии, магистр естественных наук в области стоматологии, доктор философии

Диагностическая визуализация при подготовке к дентальной имплантации

РЕЗЮМЕ. Цели. Залогом успешной имплантации зубов является правильное планирование лечения. Диагностическая визуализация стала важным средством реализации данной задачи. Традиционная рентгенография позволяет получить объективную информацию о предполагаемом месте имплантации; однако в ряде случаев ее использование не является оптимальным в связи с ограниченным размером пленки, искажением и увеличением изображения, а также возможностью получить лишь двухмерное изображение. Данная работа представляет собой обзор самых последних достижений в области применения диагностической визуализации в имплантологии, которые составляют основу совершенной подготовки к стоматологическому лечению с использованием имплантатов. ***Стратегия поиска.*** Поиск соответствующих исследований был проведен с помощью электронной базы MEDLINE по следующим ключевым словам: диагностическая визуализация в имплантологии, компьютерная томография (КТ), конусно-лучевая компьютерная томография (КЛКТ) и построение цифровой схемы имплантации. ***Результаты.*** Компьютерная томография позволяет получить трехмерное изображение анатомических структур с высоким разрешением и высокой точностью. Несмотря на то что данный метод диагностической визуализации был представлен в имплантологии около 20 лет назад, он до сих пор широко применяется для проведения самых сложных процедур. КЛКТ представляет собой усовершенствованную версию вышеописанного метода диагностики. Преимуществами КЛКТ являются конструкция аппарата, позволяющая проводить диагностику челюстно-лицевой области; низкая лучевая нагрузка; более низкая стоимость исследования и высочайшее качество снимков. Сегодня многие производители разрабатывают эти современные аппараты и дают возможность применять их в стоматологической практике. ***Выводы.*** Наряду с программным обеспечением для преобразования изображений, срезы КТ/КЛКТ обеспечивают правильный выбор размеров имплантатов и возможность прогнозировать исход лечения. Понимание современного процесса развития методов диагностической визуализации обеспечивает возможность оптимального планирования дентальной имплантации.

КЛЮЧЕВЫЕ СЛОВА: зубные имплантаты, компьютерная томограмма, цифровое построение, срез КТ, КЛКТ, конусно-лучевая КТ

TURKISH / TÜRKÇE

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İmplant Tedavisinin Planlanmasında Dental Görüntüleme

ÖZET: Amaç: İmplantların başarısında tedavinin uygun şekilde planlaması birinci plandadır. Dental görüntüleme, bu hedefin gerçekleştirilmesinde önemli bir rol oynar. Geleneksel radyografi, önerilen implant yerleri için yeterli bilgi sağlar; ancak, film boyutlarının kısıtlı olması, görüntüdeki distorsiyon, büyütme ve 2-boyutlu görüntü bazı olgularda radyografinin kullanımını sınırlar. Bu yazının amacı, implant tedavisinin ideal şekilde planlamasını kolaylaştırmak üzere en yeni ilerlemelerin bir güncellemesini sunmaktır. ***Arama Stratejisi:*** MEDLINE kullanılarak implant görüntüleme, bilgisayarlı tomografi (BT), koni ışınlı (cone beam) BT (KIBT) ve dijital implant planlama anahtar kelimeleriyle bu konuya ilişkin çalışmaları belirlemek için literatür araması yapıldı. ***Bulgular:*** Medikal BT taraması, yüksek çözünürlük ve doğrulukla anatomik alanların 3-boyutlu kopyalarını sağlar. Bu görüntüleme yöntemi implant planlamasında hemen hemen 20 yıl önce kullanıma girmiş olmakla beraber, son zamanlara kadar ancak en ileri prosedürlerin çoğunda kullanılmıştır. KIBT bu tekniğin daha da ileri bir versiyonudur. KIBT'nin avantajları arasında maksilofasiyal bölgeye özgü tasarımı, radyasyona maruz kalmayı azaltması, ve daha ekonomik ve kaliteli görüntü sağlaması sayılabilir. Günümüzde birçok şirket bu ileri teknoloji ürünü makineleri üretmekte ve diş hekimlerinin bunları çalışmalarında kullanmalarına olanak sağlamaktadırlar. ***Sonuç:*** Yazılım programlarının dönüştürülmesi ile birlikte BT/KIBT görüntüleri, implant boyutlarının seçilmesinde ve tedavi sonuçlarının önceden tahmin edilebilmesinde diş hekimlerine yardımcı olabilir. Görüntüleme tekniklerinin gelişimi konusunda güncel bilgi sahibi olmak diş hekimlerine implant terapisinin planlanmasında avantaj sağlayacaktır.

ANAHTAR KELİMELER: Dental implantlar, bilgisayarlı tomogram, dijital planlama, BT taraması, KIBT, koni ışınlı (cone beam) BT.

JAPANESE / 日本語

インプラント治療計画においてのデンタル画像

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研究概要:
目的: : インプラント成功に今以て最重視されるのは適確なインプラント治療計画で、デンタル画像はこのタスク達成に貴重なツールである。従来のレントゲンはインプラント候補部位にかろうじて適した情報を提供する；ただしフィルムサイズ制限や画像歪曲そして倍率や二次元写真などの理由で、ケースによっては用途が限定される。当文献はインプラント画像の今日の進歩について最新情報を説明し、理想的インプラント治療計画の助成を目指した。

検索法: MEDLINEに下記キーワードを入力し、当主題関連研究文献を判別した：インプラント画像、コンピュータ断層撮影(CT), コーンビーム三次元 CT (CBCT)、デジタルインプラント計画の以上である。

結果: 医療用CTスキャンは高解像度と正確性で解剖的部位の立体複写画像を提供する。この種の画像は20年程前にインプラント治療計画に導入されたものの、最近まではほとんどが進行性処置での広範囲な利用に留まっていた。CBCTはこの技術をさらに改良したバージョンである。CBCTの利点はまず顎顔面部向けに特別設計されていること、また放射線曝露量低減そして比較的安価でしかも画像品質が優れていることである。昨今は多数の企業がこうした最先端をゆく機械を開発しており、開業歯科医がオフィスで利用することも可能になってきている。

結論: ソフトウェアプログラム変換と相まって、CT/CBCT 画像はインプラントサイズ選択そして治療成果予知に役立つ可能性を呈する。画像診断の最新開発状況を把握することで、インプラント治療計画立案能力をいっそう高めることができる。

キーワード: デンタルインプラント、コンピュータ断層撮影、デジタル計画、CTスキャン、CBCT、コーンビームCT

CHINESE / 中国語

植體治療規劃的牙科造影

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摘要：
目的：種植成功的第一要務是適當的治療規劃，牙科造影則是完成此任務的重要工具。傳統 X 光可提供有關建議植牙部位充足的資訊；不過，尺寸受限、影像變形、放大倍數和平面畫面，使 X 光片的使用在某些個案受到限制。本文旨在提供植體造影的最新發展資訊，促進理想的植體治療規劃。

搜尋策略：使用 MEDLINE 進行文獻搜尋，利用植體造影、電腦斷層攝影 (CT)、椎束 CT (CBCT) 和數位種植規劃的關鍵字，找出與本主題有關的研究。

結果：醫療 CT 掃描產生準確的高解析度解剖學部位立體副本。雖然這類造影在約 20年前便開始應用在種植規劃，不過直到最近才廣泛應用在大多數先進的手術中。CBCT 是本技術的進階應用。CBCT 的優點包括適合頜面區的設計、幅射暴露量降低、較便宜以及卓越的影像品質。今天，因為許多公司都投入這類尖端機器的發展，牙醫才可能在執業時使用。

結論：與轉換軟體程式搭配時，CT/CBCT 影像可協助選擇植體尺寸並預測治療結果。瞭解造影輔助工具的最新發展，可加強我們規劃植體治療的能力。

關鍵字：牙科植體、電腦斷層攝影、數值規劃、電腦斷層掃描、CBCT、錐束CT

KOREAN / 한국어

임플란트 치료 계획에서의 치과 영상

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요약:
목적: 임플란트 치료의 성공에 있어 가장 중요한 것은 적절한 임플란트 치료 계획이라 할 수 있다. 치과 영상은 이러한 작업을 수행하는데 중요한 도구가 된다. 전통적인 방사선 촬영술을 이용하여 예정된 임플란트 시술 부위에 대한 충분한 정보를 얻을 수 있다. 그러나, 제한된 필름 크기, 영상의 왜곡, 확대 및 2-D영상 등으로 인해 그 사용이 일부 제한적이다. 본 연구의 목적은 이상적인 임플란트 치료 계획을 용이하게 하기 위한 진보된 임플란트 영상 기법의 최신 정보를 제공하는데 있다.

검색 전략: 본 연구 주제와 연관된 논문을 검색하기 위해 임플란트 영상, 컴퓨터 단층 촬영 (CT), cone beam CT (CBCT) 및 디지털 임플란트 계획을 키워드로 사용하여 MEDLINE에서 문헌 검색을 수행하였다.

결과: 의학적 CT 스캔은 높은 해상도와 정확성을 갖는 해부학적 영역의 3차원 모형을 생성시킨다. 이러한 유형의 영상은 약 20년 전에 임플란트 계획에 도입되었으나, 최근에는 대부분의 진보된 시술법에 널리 이용되어 왔다. CBCT 는 이러한 기술을 보다 더 발전시킨 것이다. CBCT의 장점은 악안면 영역을 위해 고안된 특별한 디자인, 방사선 노출량의 감소, 저렴한 가격 및 영상의 우수한 품질에 있다. 오늘날 많은 회사들이 이러한 최첨단 기계를 개발하고 있으며, 임상 현장에서의 이용을 가능하게 하고 있다.

결론: 소프트웨어 프로그램의 전환으로, CT/CBT 영상은 임플란트의 규모 및 치료 결과를 예측하는데 도움이 될 수 있다. 따라서 영상에 대한 최신 발전상을 이해하는 것은 임플란트 치료 계획의 능력을 강화시킬 수 있을 것으로 생각된다.

키워드: 치과 임플란트, 컴퓨터 단층 촬영, 디지털 계획, CT 스캔, CBCT, Cone beam CT