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REVIEW

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State-of-the-art on cone beam CT imaging for preoperative planning of implant placement

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Abstract Orofacial diagnostic imaging has grown dramatically in recent years. As the use of endosseous implants has revolutionized oral rehabilitation, a specialized technique has become available for the preoperative planning of oral implant placement: cone beam computed tomography (CT). This imaging technology provides 3D and cross-sectional views of the jaws. It is obvious that this hardware is not in the same class as CT machines in cost, size, weight, complexity, and radiation dose. It is thus considered to be the examination of choice when making a risk–benefit assessment. The present review deals with imaging modalities available for preoperative planning purposes with a specific focus on the use of the cone beam CT and software for planning of oral implant surgery. It is apparent that cone beam CT is the medium of the future, thus, many changes will be performed to improve these. Any adaptation of the future systems should go hand in hand with a further dose optimalization.

Keywords Cone beam computed tomography · 3-D imaging · Dental implants · Preoperative planning · Volumetric tomography

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Oral rehabilitation by means of implants

The introduction of endosseous implant treatment has initiated a revolution in oral rehabilitation for both partially and fully edentulous patients. The clinical application of the concept of osseointegration introduced in the midsixties [7] soon revealed a predictable long term success [24]. Nowadays the use of implants is even popular for the replacement of a single missing tooth [5].

Only an exhaustive and comprehensive radiological assessment can provide the necessary information to select such optimal sites and the number and size of implants to be placed. The selection of the radiological technique should be based on weighing the required image quality against the radiation risks and costs involved [20]. In the perspective of implant surgery, a correct identification of some anatomic structures such us the mandibular canal is important to avoid nerve damage or other perioperative complications.

In a position paper by the American Academy of Oral and Maxillofacial Radiology, Tyndall and Brooks [39] recommend that conventional *cross-sectional tomography* should be the method of choice for most implant patients. Nevertheless, the authors state that currently there is no scientific evidence for their recommendation. The ideal goal of the radiographic examination is to achieve as much information on the jawbone as possible and at the same time minimize the radiation burden to the patient regarding the ALARA principle (as low as reasonably achievable) and the costs. Thus one could argue that while firm arguments are missing, one should refrain from such supplementary imaging.

Another set of guidelines was introduced by the European Association of Osseointegration (EAO) to avoid any overconsumption of radiographic methods. These EAO guidelines also focus on cross-sectional imaging but leave to the discretion of the clinician the use of 2-D imaging in minor and/or established low risk surgery [12].

Computed tomography is a very common imaging technique, which allows the capture of information through a spiral movement of the radiation source and the detectors around the region of interest. For maxillofacial applications, dedicated software was developed capable of reformatting the data of the axial slices into panoramic images and multiplanar cross-sectional images [38].

The advantages offered by computed tomography (CT) technology are direct volumetric reconstructions, and faster and easier data transformation for use in 3-D analyses including functional imaging and real time imaging for guiding interventional procedures [9].

On the other hand, CT sections impart relatively high radiation doses to the patient. This radiation dose has to be balanced by the required information for implant placement. Its use can seldom be justified except for the imaging of large jawbone segments. A further development and improvement of CT equipment has inspired researchers and clinicians to use it as low-dose CT [25]. This is where the cone beam CT may offer a promising alternative approach.

Today the availability of real 3-D planning software, which furthermore allows a reliable transfer to the surgical field through drilling templates, helps the surgeon to achieve an adequate oral implant placement [40].

The present review deals with imaging modalities available for preoperative planning purposes with a specific focus on the use of the cone beam CT and software for planning of oral implant surgery.

Cone beam computed tomography

A new type of CT machine devoted to the imaging of maxillofacial structures based on the cone beam CT (CBCT) technique was developed. Such cone beam system allows the physician to acquire 3-D volume data in one rotation at reasonably low levels of radiation dosage.

The CBCT technique was employed previously in radiotherapy using fluoroscopic systems or modified simulators to obtain cross-sections of the patient in the same geometric conditions as the treatment. It was also used in vascular imaging and in microtomography of small specimens for biomedical and industrial applications [28]. Nowadays, radiotherapy has become another relevant field for this machine.

Megavoltage cone beam CT is an imaging technique for image-guided radiotherapy that will enable radiation oncologists to enhance the care for cancer patients by generating superior digital images and developing, simulating, and verifying treatment plans [32]. Another application includes stereotactic intracranial radiation therapy and prostate radiation therapy [31]. Moreover, Sarkar et al. [33] have reported cone beam CT application in several fields such as the space, defense, automobile, nuclear industry, etc.

Mozzo et al. [28] presented the first commercial CBCT system (NewTom DVT 9000, Quantitative Radiology, Verona, Italy) devoted to maxillofacial imaging. This same company has recently developed a new model named NewTom 3G. Besides the latter, we can presently find four other models: I-CAT (Imaging Sciences International, Hatfield, USA), 3D Panoramic X-ray CT scanner PSR 9000N (Asahi Roentgen, Kyoto, Japan), CB MercuRay (Hitachi Medico Technology Corporation, Kashiwa, Chiba, Japan), and 3D Accuitomo (J. Morita, Kyoto, Japan). Specifications of these cone beam devices devoted to dentistry are shown in Table 1.

The latter machine, the 3D Accuitomo was developed by remodeling the "Multi-functional Panoramic Tomography" (Scanora, Soredex, Helsinki, Finland). The 2003 annual

Table 1 Company, x-ray source voltage, X-ray source current (x time), scanning time, in plane voxel size and reconstruction increment for each cone beam CT device

Cone beam CT devices	Company	Size of reconstructed image (diameter × height)	X-ray source voltage (kV)	X-ray source current (× time) mA(s)[a]	Scanning time(s)	Voxel size (xy)[c]	Min reconstruct. Incr.[1] or cubic[2]
3D Accuitomo	J. Morita, Kyoto, Japan	4×3, 4×4, 6×6	60–80 (step 1kV)	1–10 mA (step 0.1 mA)	18	0.125	0.125[1]
NewTom 9000	Quantitative Radiology, Verona, Italy	13×13	110	15 mA[b]	72	0.29	0.2[1]
NewTom 3G		8×8, 10×10, 13×13, 15×15, 18×18, 22×22	110	15 mA[b]	36	0.16–0.42	0.16[1]
I-CAT	Imaging Sciences, Hatfield, Pennsylvania, USA	16×21, 16×13, 16×8, 16×8	120	12.48 mAs, 23.87 mAs, 46.72 mAs	10, 20, 40	0.2–0.4	0.2[2]
CB MercuRay	Hitachi, Medical, Kyoto, Japan	5.12×5.12, 10.2×10.2, 15×15, 19×19	60–120 (step 20 kV)	10 or 15 mA	10	0.1–0.4	0.1[2]
3D Panoramic X-ray CT scanner PSR 9000N	Asahi Roentgen, Kyoto, Japan	3.6×4, 4.1×4	60–100 (step 1 kV)	2–12 mA (step 2 mA)	20, 30	0.1–0.15	0.1–0.15[2]

[a] Because not all companies provide both the mA and the mAs, this distinction is made
[b] This is the maximum mA setting. The mA is calculated based on the size of the patient head, calculated based on two scout views
[c] These voxel sizes give the range of the different possibilities. There is no direct link between the information given about the reconstructed size and these voxel sizes. Only a select combination of possibilities of both columns is possible

report of the 3D Accuitomo device found a high demand of scans for implant treatment; 53% of the total cases were devoted to oral implant presurgical and postsurgical evaluation [37] (Fig. 1).

Various factors such as accuracy of the images and radiation dose should dictate the choice of the most adequate imaging technique. These elements will be discussed below.

Image quality on cone beam computed tomography

It was established that the generation of the CT hardware, data acquisition, and parameters such as slice thickness and interval of the reconstruction can determine the imaging resolution. Schulze et al. [35] demonstrated high-contrast structures with the CBCT device. In addition, several authors [13, 18, 29] revealed excellent image acquisition for different structures such as morphology of the mandible, location of the inferior alveolar canal, and even for the relationship of radioopaque templates to the bone.

Recently, CT and CBCT technique were compared to assess which one was the most reliable. Kobayashi et al. [22] confirmed the superiority of PSR 9000 cone beam CT to spiral CT in terms of spatial resolution on cross-sectional images.

Similar findings were reported when comparing images from an anthropomorphic phantom taken by both the 3DX Multi Image Micro CT (J. Morita) and the multidetector Aquilion Multi-Slice CT (Toshiba Medical Co Ltd, Tokyo, Japan). The superiority of the 3DX cone beam device in the images' resolution was demonstrated by means of a high resolution score of the periodontal ligament space and the lamina dura [13].

Honda et al. [16] compared helical CT with the Ortho-CT and reported that the image quality obtained with the Ortho-CT far surpassed that of the helical CT.

To achieve accurate information and sufficient detail for preoperative planning of implant surgery, image quality of the different devices should be analyzed. Hirsch et al. [15] made a comparative investigation of the image quality using three different X-ray systems. Five human cadaver heads were examined by spiral CT (Somatom Emotion; Siemens, Erlangen, Germany), cone beam CT (NewTom DVT 9000) and 3D Accuitomo. Image quality assessment was performed by five different observers using a 5-point rating scale. The study revealed that the best image quality (mean score 4.62) was achieved with the 3D Accuitomo. Spiral CT (mean score 2.78) and NewTom DVT 9000 (mean score 2.91) were similar regarding the visibility of interesting structures.

Recently, Lascala et al. [23] have shown the reliability and accuracy of the NewTom DVT 9000 when measuring anatomical structures from CBCT images and compared them with measurements of real distances of eight dry skulls.

Brooks et al. [8] evaluated images of five unembalmed cadaver heads and three living humans. The mandibular canal could be seen easily in the scans of the humans but was not readily visible with the default image reconstruction algorithm on the scans of the cadavers. This was the result of the age of the specimens and the effect of the

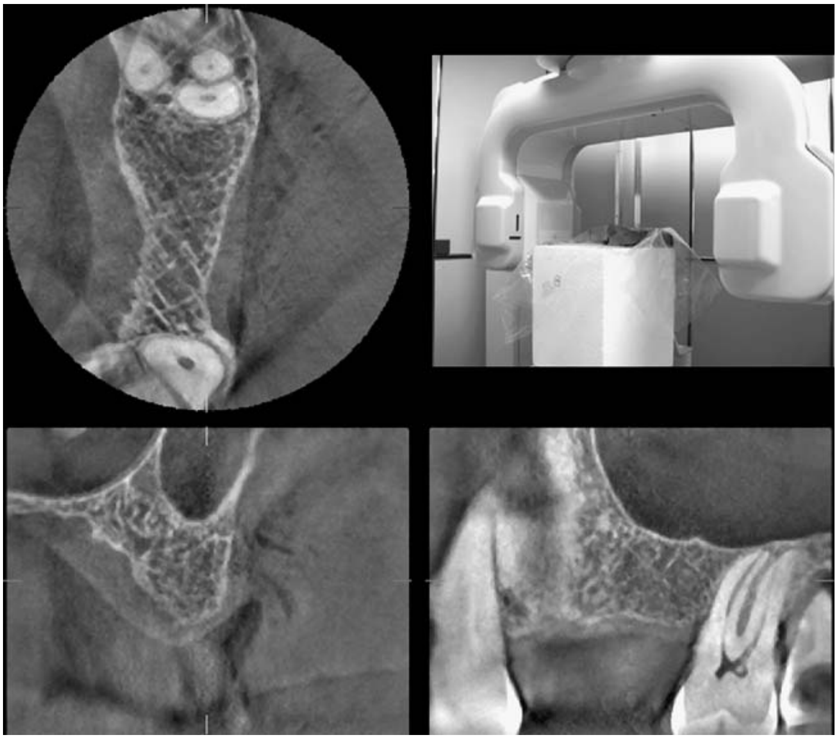

Fig. 1 Scans for implant treatment

thawing process on the visualization of the anatomical structures.

Radiation doses using cone beam computed tomography

In the field of diagnostic imaging, it is critical that the patient-benefit of a procedure outweighs the risk of exposure to ionizing radiation. Because one clear advantage of CBCT over conventional CT scanners is its lower radiation dose, it is essential to determine the effective dose of the various CBCT scanners vs CT as they come into common use. Mishima et al. [27] reported an advantage on the exposure values of the 3D Panoramic X-ray CT scanner PSR 9000N. The integral absorbed dose of radiation was less than 1/15 that of spiral CT, at least when the exposure condition of the latter was optimized, to obtain a thinner slice width and a more accurate data.

Ludlow et al. [26] have made a recent dosimetry comparison between two cone beam devices: I-CAT and NewTom 3G (Quantitative Radiology). The effective dose for the former was 101.5 μSv using the 2005 tissue weights. The operating parameters were 120 kVp and 22.85 mAs. The effective dose for the NewTom 3G using the same phantom and full field of view (FOV) was 56.5 μSv. The operating factors were 110 kV and 8.1 mA as determined automatically after a prescan of the phantom. From this study, it seems that the effective dose from the I-CAT is 1.6–1.8 times that of the NewTom 3G.

There are few surveys on dosimetry of the 3D Accuitomo. Iwai et al. [19] estimated the effective dose of Ortho-CT, the first prototype of this device. They found that the skin dose was almost the same as with rotational panoramic radiography. This means an effective dose of approximately 20 μSv. Published effective doses from digital panoramic radiography range from 4.7 to 14.9 μSv per scan [11]. Other published data on nondigital panoramic radiographs puts the effective dose as high as 26 μSv. Afterwards, Arai et al. [1] found that the effective dose in one projection by the 3DX MultiImage Micro-CT was 7.4 μSv. More research is however needed to verify such results for all systems available. Table 2 shows the equivalent background dose for imaging techniques usually selected for the preoperative planning of oral implants.

Table 2 Relative background radiation estimations for cone beam versus spiral CT

Imaging technique	Equivalent natural radiation estimations (days) [11, 25, 26]
CT mandible + maxilla	38
CT mandible	33
CT maxilla	26
Cone beam CT	6–12
Panoramic radiograph	0.5–2

Shortcomings of cone beam computed tomography

It should be noted that cone beam CT devoted to the maxillofacial area was designed to scan jaw bone lesions. Cancellous bone in particular is sharply visualized. Kobayashi et al. [22] reported that one of the drawbacks of the 3D Panoramic X-ray CT scanner PSR 9000 was its inability of discriminating soft tissue because of its low contrast resolution. Furthermore, Heiland et al. [14] could not report information about soft tissue quality. However, this device provides essential information about the osseous morphology for planning the placement of oral implants including cortical integrity and thickness enlarged bone marrow spaces, postextraction irregularities, and trabecular bone density.

When comparing CT with cone beam CT reconstructed images, CT scans showed the most suitable images for tumor-derived alterations due to their capacity for soft tissue reconstruction. On the other hand, cone beam CT could only visualize primary osseous tumors or soft tissue tumors via osseous destruction of an impinging tumor [36].

One of the characteristics of these cone beam CT systems is their option to select the region of interest in accordance with the clinical demands. Unfortunately, not all systems have this quality. The 3D Accuitomo, for instance, only allows scanning of limited volumes (*Ø* 4 cm, *h* 3 cm). One of the machines that have large field of view is NewTom DVT 9000, which in addition to both jaws, can display both temporo-mandibular joints and the sinus.

It is known that noise decreases with increasing voxel size and with increasing beam current [2]. Therefore, a high quality of reconstructed images is related to less noise with neither streak nor ring artifact findings. Metallic dental fillings may create artifacts in cone beam CT images. In addition, Mozzo et al. [28] found that the lower absorbed dose in the NewTom DVT 9000 was explained partially by the slightly higher level of accepted noise in the images.

It can also be argued that the image noise of CB MercuRay is higher than of conventional helical CT. This is likely to result from the noise of the image intensifier and scattered radiation of this system [2].

Moreover, by irradiating only one site or area, such as with the cone beam CT, projections acquired do not contain the entire object. Reconstructed images thus suffer from truncation artifacts. To solve this problem, Wiegert et al. [44] have presented a novel method to avoid such truncated artifacts using a truncation-free volume data for accurate compensation of the artifacts.

In the CBCT systems that were developed, detection was accomplished by the combination of an X-ray image intensifier and Charge Coupled Device camera. This type of detector was shown to be an effective aid on imaging technology for acquiring 3-D data for diagnostic tasks such as implant treatment planning [17, 45]. At the same time, a prototype CBCT with a flat panel-type detector (FPD) was developed and compared with an image-intensifier detector [3]. Once the results showed that FPD system has a strong potential for use as a cone beam CT detector, they have evaluated the system performance. High-resolution recon-

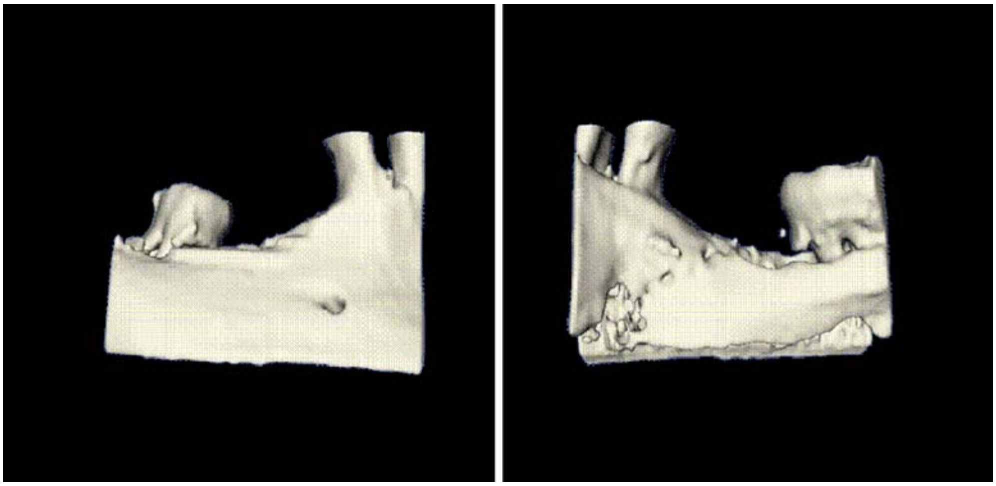

Fig. 2 Image segmentation to construct 3-D models of the bone and prosthesis

structed images were reported in this study. Finally, they concluded that a FPD offers improved precision in maxillary imaging [4].

Case report

Axial, sagittal and coronal images of a dry mandible were acquired with 3D Accuitomo (see Fig. 1). The first scan was taken while the partial edentulous mandible was positioned wearing the scan template. The exposure parameter settings selected included 70 Kv and 2 mA. A second scanning of the template alone was also required. Scanning parameters were now lowered to 60 kV and 1 mA to allow visibility of the template. The exposure time was of 17.5 s and a 360-degree-turn was selected.

The bone in the image was semi-automatically segmented with the Amira 3D (Mercury Computer System, Berlin, Germany). Automatic bone segmentation was not possible because of a bias field of the image intensity (Fig. 2).

Three-dimensional computed tomography-based planning

Various studies have investigated the efficiency of preoperative CTs for the success of surgical treatments. Precise insertion of the implant can be obtained through the use of image-based surgical templates, modified conventional tomography, CT-scans, and 3-D computer-assisted planning of oral implant surgery [6, 10, 21, 30]. These methods are helpful but not sufficient to accurately transfer the preoperatively acquired data to the patient.

Advances in computer technology have enabled the development of systems that can assist the clinician in diagnosis, treatment planning, and the treatment itself. Three-

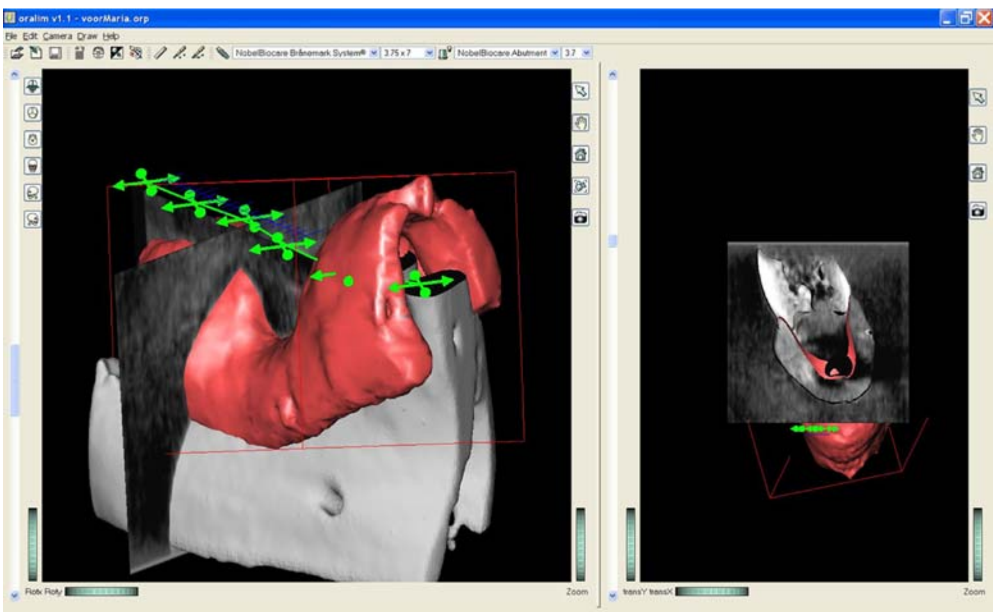

Fig. 3 Osseous tissues in relation to the position of denture teeth

dimensional computer-assisted interactive implant planning has the accuracy and reliability required for clinical use. Two methods for a computed-based transfer are available: navigation and stereolithographic drill guides.

Navigation was primarily used in neurosurgery, orthopedic surgery, otorhinolaryngological surgery, and maxillofacial surgery [43]. This technology offers the surgeon precise views of preplanned locations in the patient's jaw during surgery, demonstrating an accurate transfer of the preoperative plan to the patient [42].

Another approach is the use of stereolithographic drill guides. Some authors [40] reported angular deviation usually bellow 3° and linear deviations mainly below 2.5 mm for zygomatic implants when employing stereolithographic drill guides. Furthermore, several authors demonstrate how implant placement was improved by using stereolithographic surgical guides [34, 41].

Different softwares for preoperative planning purposes are available. Procera Software (Nobelbiocare, Göteborg, Sweden) allows the clinicians to evaluate the osseous tissues in relation to the position of denture teeth (Fig. 3). Vimplant (CyberMed, Inc, Seoul, Korea) is another software program that allows interactive 2-D and 3-D diagnosis and treatment planning and could help the clinician to easily and quickly visualize all of the images, which may exist in the film version of the CT Scan. There are several more but this goes beyond the goal of the present paper.

Furthermore, several navigation softwares are available. VISIT was developed at the Department of Biomedical Engineering and Physics (University of Vienna, General Hospital, Vienna, Austria).

RoboDent (GmbH, Berlin, Germany) and Stryker Leibinger (Freiburg, Germany) are implant planning and navigation systems. With the help of 3-D computer guidance, oral implants can be placed according to the planning with high precision.

Conclusions

The use of 2-D or 3-D CT image-based planning for oral implant treatment is now widespread. These methods are helpful in the preoperative evaluation of the surgical site. They also enhance the surgeons' knowledge of specific anatomic situation criteria.

Dose radiation received from a reformatted CT examination of the mandible or maxilla is the same whether a single implant site or multiple sites are evaluated. Therefore, CT will be indicated only for anatomically difficult cases or with extensive implant treatment.

The wide range of potential applications of CBCT was shown in several clinical cases. Thus, CBCT provides an option for digital 3-D imaging with a significantly smaller effective dose than that achieved with CT and is within the range of traditional dental imaging modalities.

Image quality and radiation dose in CBCT devices makes these devices very attractive for presurgical planning approaches. Considering the increased interest in cone beam CT, further adaptations, optimalizations, and new developments will soon follow. The future may offer fully adaptable systems regarding exposure parameters and scanning volumes and image quality improvements. The evolution in hardware will be followed by a refinement of the software including dedicated surgical tools such as preoperative implant planning software.

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References

1. Arai Y, Honda K, Iwai K, Shinoda K (2001) Practical model "3DX" of limited cone-beam X-ray CT for dental use. Int Congr Ser 1230:713–718
2. Araki K, Maki K, Seki K, Sakamaki K, Harata Y, Sakaino R, Okano T, Seo K (2004) Characteristics of a newly developed dentomaxillofacial X-ray cone beam CT scanner (CB MercuRay): system configuration and physical properties. Dentomaxillofac Radiol 33:51–59
3. Baba R, Konno Y, Ueda K, Ikeda S (2002) Comparison of flat-panel detector and image-intensifier detector for cone-beam CT. Comput Med Imaging Graph 26:153–158
4. Baba R, Ueda K, Okabe M (2004) Using a flat-panel detector in high resolution cone beam CT for dental imaging. Dentomaxillofac Radiol 33:285–290
5. Belser U, Schmit B, Higginbottom F, Buser D (2004) Outcome analysis of implant restorations located in the anterior maxilla: A review of the literature. Int J Oral Maxillofac Implants 19:30–42 (Suppl)
6. Besimo C, Lambrecht JT, Guindy JS (2000) Accuracy of implant treatment planning utilizing template-guided reformatted computed tomography. Dentomaxillofac Radiol 29:46-51
7. Brånemark P-I, Breine U, Adell R, Hanson Bo, Lindström J, Ohlsson A (1969) Intraosseous anchorage of dental prostheses. Scand J Plast Reconstr Surg 3:81–100
8. Brooks SL, Beason R, Sarment D, Sukovic P (2004) Implant imaging with the I-CAT cone-beam CT-a progress report. Int Congr Ser 1268:1184–1186
9. Cavalcanti MGP, Rocha SS, Vannier MW (2004) Craniofacial measurements based on 3D-CT volume rendering: implications for clinical applications. Dentomaxillofac Radiol 33:170–176
10. Fortin T, Coudert J, Champleboux G, Sautot P, Lavallee S (1995) Computer-assisted dental implant surgery using computed tomography. J Image Guid Surg 1:53–58
11. Gijbels F, Jacobs R, Debaveye D, Verlinden S, Bogaerts R, Sanderink G (2005) Dosimetry of digital panoramic imaging. Part 1: patient exposure. Dentomaxillofac Radiol 34:145–149
12. Harris D, Buser D, Dula K et al (2002) E.A.O Guidelines for the use of Diagnostic Imaging in Implant Dentistry. Clin Oral Implants Res 566–570
13. Hashimoto K, Arai Y, Iwai K, Araki M, Kawashima S, Terakado M (2003) A comparison of a new limited cone beam computed tomography machine for dental use with a multidetector row helical CT machine. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 95:371–377
14. Heiland M, Schmelzle R, Hebecker A, Schulze D (2004) Intraoperative 3D imaging of the facial skeleton using the SIREMOBIL Iso-C^{3D}. Dentomaxillofac Radiol 33:130–132
15. Hirsch E, Graf H-L, Hemprich A (2003) Comparative investigation of image quality of three different X-ray procedures. Dentomaxillofac Radiol 32:201–211
16. Honda K, Arai Y, Iwai K, Hasimoto K, Saito T, Shinoda K (2000) Fundamental efficiency of new-style limited cone-beam CT (3DX). Comparison with Helical CT. Jpn J Tomogr 27:17–22

17. Honda K, Larheim A, Johannessen S, Arai Y, Shinoda K, Westesson P (2001) Ortho cubic super high resolution computed tomography: a new radiographic technique with application to the temporomandibular joint. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 91:239–243
18. Ito K, Gomi Y, Sato S, Arai Y, Shinoda K (2001) 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 12:539–542
19. Iwai K, Arai Y, Nishizawa K,Tammisalo E, Hashimoto K, Shinoda K (1998) Estimation of radiation doses from ortho cubic super high resolution CT. Dentomaxillofac Radiol 27 [Suppl 1]:39
20. Jacobs R, Gijbels F (2000) Oral Imaging 2000. KULeuven, Dept Periodontology, Leuven, pp 4–8
21. Jacobs R, Adriansens A, Verstreken K, Suetens P, van Steenberghe D (1999) Predictability of a three-dimensional planning system for oral implant surgery. Dentomaxillofac Radiol 28:105–111
22. Kobayashi K, Shimoda S, Nakagawa Y, Yamamoto A (2004) Accuracy in measurement of distance using limited cone-beam computerized tomography. Int J Oral Maxillofac Implants 19:228–231
23. Lascala CA, Panella J, Marques MM (2004) Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillofac Radiol 33:291–294
24. Lindquist LW, Carlsson GE, Jemt T (1996) A prospective 15-year follow-up study of mandibular fixed prostheses supported by osseointegrated implants. Clinical results and marginal bone loss. Clin Oral Implants Res 7:329–336
25. Loubele M, Schutyser F, Debaveye D, Jacobs R, Bogaerts R, Maes F, van Cleynenbreugel J, Vandermeulen D, Marchal G, Suetens P (2005) Radiation dose versus image quality for low-dose CT protocols of the head for maxillofacial surgery and dental implant planning. Radiat Prot Dosim (International workshop on optimisation of dose and performance in interventional and digital imaging-DIMOND III, March 25–27, 2004, Leuven, Belgium) (in press)
26. Ludlow JB, Brooks SL, Davies-Ludlow LE, Howerton WB (2005) Dosimetry of 3 CBCT units for oral and maxillofacial radiology. 15th International Congress of DentoMaxilloFacial Radiology. OP22, p 53
27. Mishima A, Kobayashi K, Yamamoto A, Kimura Y, Tanaka M (2001) Comparison of patient radiation dose from dental CT and spiral CT. Symposium of high technology research center in Tsurumi University School of Dental Medicine. Nagasue Shoten, Yokohama, Japan, pp 171–172
28. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA (1998) A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur Radiol 8:1558–1564
29. Nakagawa Y, Kobayashi K, Mishima, Ishii H, Asada K, Ishibashi K (2002) Preoperative application of limited cone beam computerized tomography as an assessment toll before minor oral surgery. Int J Oral Maxillofac Surg 31:322–327
30. Naitoh M, Arjji E, Okumura S, Ohsaki C, Kurita K, Ishigama T (2000) Can implants be correctly angulated based on surgical templates used for osseointegrated dental implants? Clin Oral Implants Res 11:409–414
31. Oldham M, Letourneau D, Watt L, Chen P, Martinez A, Wong J (2003) On-line volumetric CT-guided radiation theraphy. Int J Rad Onc Biol Phys 57:184 (Suppl)
32. Pouliot J, Xia P, Aubin M, Verhey L, Bani-Hashemi A, Ghelmansarai F, Mitschke M, Svatos M (2003) Low-dose megavoltage cone beam CT for dose-guided radiation therapy. Int J Rad Onc Biol Phys 57:183 (Suppl)
33. Sarkar PS, Sinha A, Kashyap Y, More MR, Godwal BK (2004) Development and characterization of a 3D cone beam tomography system. Nucl Instr Meth A 524:377–384
34. Sarment D, Sukovic P, Clinthorne N (2003) Accuracy of implant placement with astereolithographic surgical guide. Int J Oral Maxillofac Implants 18:571–577
35. Schulze D, Heiland M, Schmelzle R, Rother UJ (2004) Diagnostic possibilities of cone-beam computed tomography in the facial skeleton. Int Congr Ser 1268:1179–1183
36. Schulze D, Heiland M, Thurmann H, Adam G (2004b) Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography. Dentomaxillofac Radiol 33:83–86
37. Shinoda K, Honda K, Matsumoto K, Arai Y (2004) Annual report of limited cone beam computed tomography (3D Accu-I-Tomo) from 3000 cases at Nihon University dental hospital in 2003. Int Congr Ser 1268:1187–1191
38. Schwarz MS, Rothman SL, Chafetz N, Rhodes M (1989) Computed tomography in dental implantation surgery. Dent Clin North Am 33:555–597
39. Tyndall AA, Brooks SL (2000) Selection criteria for dental implant site imaging: a position paper of the American Academy of Oral and Maxillofacial Radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 89:630–637
40. van Steenberghe D, Naert I, Andersson M, Brajnovic I, Van Cleynenbreugel J, Suetens P (2002) A custom template and definitive prosthesis allowing immediate implant loading in the maxilla: a clinical report. Int J Oral Maxillofac Implants 17:663–670
41. van Steenberghe D, Ericsson I, Van Cleynenbreugel J, Schutyser F, Brajnovic I, Andersson M (2004) High precision planning for oral implants based on 3-D CT scanning. A new surgical technique for immediate and delayed loading. Appl Osseointegration Res 4:27–31
42. Wanschitz F, Birkfellner W, Watzinger F, Schopper C, Patruta S, Kainberger K, Figl M, Kettenbach J, Bergmann H, Ewers R (2002) Evaluation of accuracy of computer aided intraoperative positioning of endosseous oral implants in the edentulous mandible. Clin Oral Implants Res 13:59–64
43. Watzinger F, Wanschitz F, Wagner A, Enislidis G, Millesi W, Baumann A, Ewers R (1997) Computer-aided navigation in secondary reconstruction of post-traumatic deformities of the zygoma. J Craniomaxillofac Surg 25:198–202
44. Wiegert J, Bertram M, Wulff J, Schafer D, Weese J, Netsch T, Schomberg H, Rose G (2004) 3D ROI imaging for cone-beam computed tomography. Int Congr Ser 1268:7–12
45. Ziegler CM, Woertche R, Brief J, Hassfeld S (2002) Clinical indications for digital volume tomography in oral and maxillofacial surgery. Dentomaxillofac Radiol 31:126–130