THEMATIC ABSTRACT REVIEW

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Current Role of Cone-Beam Imaging Tomography in Implant Dentistry

While computed tomography (CT) has been used in implant dentistry for some time, there has been a recent increased interest with the advent of cone-beam CT (CBCT) imaging systems. With improved image resolution and a reduced dose, CBCT holds promise relative to medical CT imaging. However, the cost-benefit ratio must be taken into consideration and adjusted based on the diagnostic needs of each individual patient. In some systems, CBCT has limitations in imaging soft tissue volumes and quality. Conventional CT imaging is more appropriate for tumor-associated radiolucency, for example.

A search of the literature was conducted using PubMed with medical subject headings (MeSH) of Dental Implants and Computed Tomography. The search was limited to research published in 2006 or 2007; studies published in *The International Journal of Oral & Maxillofacial Implants* were excluded.

A number of new and revised CBCT systems are coming on the market. Despite the popularity of CBCT, a few studies have been published in the past 2 years addressing the accuracy, resolution, or patient-specific technical issues with these systems. The majority of reports were individual case reports, with an emphasis on procedural aspects or radiographic guide fabrication. The studies chosen for inclusion in the present review were either well-done reviews for this emerging field or small case series that attempted to address issues such as patient positioning, scatter artifact, and accuracy of implant placement using CBCT imaging studies. Pinsky et al explored the issue of lesion detection on CBCT images using an in vitro approach and found a small reduction in size resolution with greater variability when using automated algorithm measurements. Mengel et al showed the improved resolution of CBCT volume studies of osseous defects in bone over conventional forms of imaging, especially for periodontal wall defects. Dantas et al addressed the issue of patient positioning and indicated a range of about 19 degrees of jaw positioning to maintain accuracy of scanning, while Jaekel and Reiss explored the issue of metal artifact scatter and the influence this has on imaging as well as potential radiotherapy. Van Steenberghe et al presented the early results of a small multicenter trial of 1 implant system showing promising results. As the field of imaged-based treatment planning expands, we will see enhanced use of stereolithographic reconstructions. Although they provide valuable information, they can create artifacts and variable implant positioning, as shown by Di Giacomo et al. Finally, combining imaging with surgical navigation is an interesting application of this technology. Certain aspects, such as variability in implant placement, are being improved, as shown by Mischkowski et al.

Clinical trials are needed to document the emerging use of CBCT in conjunction with computer-based treatment planning and perhaps with image-based surgery. Other issues for future research and clinical consideration include the role of patient movement relative to long scan times (eg, 10 to 40 seconds); decreased soft tissue imaging capability; radiation exposure especially in a growing child; cost-benefit ratio; the role of pathology within the field of interest; and the role of oral maxillofacial radiologists.

Guerrero ME, Jacobs R, Loubele M, Schutyser F, Suetens P, van Steenberghe D. State-of-the-art on cone beam CT imaging for preoperative planning of implant placement. Clin Oral Invest 2006; 10:1–7.

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 (CBCT). This imaging technology provides 3-dimensional 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 focus on the use of CBCT and software for planning of oral implant surgery. It is apparent that CBCT is the medium of the future; thus, many changes will be performed to improve the these systems. Any adaptation of the future systems should go hand-in-hand with further dose optimalization. (GUERRERO/STANFORD)

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Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofac Radiol 2006;35:410–416.

Lesions causing intraosseous defects in the head and neck region are difficult to diagnose using 2-dimensional radiography, and 3-dimensional (3D) data provided by computed tomography (CT) is useful but often difficult to obtain. Recently, cone-beam CT (CBCT), which has the potential to become a practical tool in dentistry, was made available. However, there is limited evidence to prove that defect volume can be determined accurately. Therefore, this in vitro validation study aimed at establishing whether linear and 3D CBCT, using volumetric measurements, is accurate for determining osseous defect sizes. Depth and diameter of simulated bone defects in *(1)* an acrylic resin block and *(2)* a human mandible were blindly measured electronically by 5 examiners using CBCT. Linear measurements were compared with predetermined machined dimensions. Using software, volume extraction was performed by another examiner on the acrylic resin phantom and compared with known dimensions. Data were analyzed using paired t tests. Using the acrylic resin block, mean width accuracy was −0.01 mm (± 0.02 SE) and mean height difference was −0.03 mm (± 0.01 SE; $P > .05$). For the human mandible, mean width accuracy was −0.07 mm (± 0.02 SE), and mean height accuracy was −0.27 mm (± 0.02 SE; $P < .01$). Volume accuracy was −6.9 mm^3 (± 4 SE) for automated calculations and −2.3 mm^3 (± 2.6 SE) for the manual measurements ($P < .001$). CBCT has the potential to be an accurate, noninvasive, practical method to reliably determine osseous lesion size and volume. Further clinical validation will lead to a vast array of applications in oral and maxillofacial diagnosis. (PINSKY/STANFORD)

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Mengel R, Kruse B, Flores-de-Jacoby L. Digital volume tomography in the diagnosis of peri-implant defects: An in vitro study on native pig mandibles. J Periodontol 2006;77:1234–1241.

The aim of this study of native pig mandibles was to investigate the accuracy and quality of the representation of peri-implant defects by intraoral radiography (IR), panoramic radiography (PR), computerized tomography (CT), and digital volume tomography (DVT). The examination was carried out on 19 native pig mandibles. In the toothless sections of the mandibles, 1 or 2 implants were inserted. Following standardized preparation of the peri-implant defects (11 each of dehiscences, fenestrations, and 2- to 3-walled intrabony defects), IR, PR, CT, and DVT were performed. The peri-implant defects were measured using appropriate software on the digitized IR and PR image programs. As a control method, the peri-implant bone defects were measured directly using a reflecting stereomicroscope with an ocular measurement piece. The statistical comparison between the measurements of the radiographic scans and those of the direct readings of the peri-implant defects was performed with Pearson's correlation coefficient. The quality of the radiographic scans was determined through the subjective perception and detectability of the peri-implant defects by 5 independent observers. In the DVT and CT scans, it was possible to measure all the bone defects in 3 planes. Comparison with the direct peri-implant defect measurements yielded a mean deviation of 0.17 ± 0.11 mm for the DVT scans and 0.18 ± 0.12 mm for the CT scans. On the IR and PR images, the defects could be detected only in the mesio-distal and cranio-caudal planes. In comparison with the direct measurements of the peri-implant defects, the IR images revealed a mean deviation of 0.34 ± 0.30 mm, and the PR images revealed a mean deviation of 0.41 ± 0.35 mm. The quality rating of the radiographic images was highest for the DVT scans. Overall, the CT and DVT scans displayed only a slight deviation in the extent of the peri-implant defects. Both radiographic imaging techniques permitted imaging of peri-implant defects in 3 planes, true to scale and without overlay or distortion. The DVT scans showed the best imaging quality. (MENGEL/STANFORD)

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Dantas JA, Montebello Filho A, Campos PS. Computed tomography for dental implants: The influence of the gantry angle and mandibular positioning on the bone height and width. Dentomaxillofac Radiol 2005;34:9–15.

The purpose of this study was to investigate the effect of deviation of mandibular positioning, by changing the gantry angle, on the measured height and width of dental implant sites in reformatted cross-sectional computed tomography (CT) scans. CT images of 10 human dry mandibles were made in 3 gantry positions to simulate changes in patient positioning: *(1)* parallel to the lower base of the mandible (standard); *(2)* with a gantry inclination of +19 degrees; and *(3)* with an inclination of −19 degrees. One examiner measured the bone height and width at selected sites in the images at 3 different times. Results were compared with a paired test in SAS 8.02. In relation to bone height, when the jaws were inclined to the inferior direction (gantry angle +19 degrees), there was no statistically significant difference for any region studied. There was a statistically significant difference for the incisor region when the jaws were inclined to the superior direction (gantry angle −19 degrees). With respect to the width of the bone rim, there was a statistically significant difference only for the molar region when the jaw was inclined to the inferior direction and for the canine region when the inclination was to the superior direction. Errors in mandibular positioning of 19 degrees produced image discrepancies with regard to bone height and width which were not excessive. Thus, examinations do not have to be repeated owing to variation of mandibular positioning, because the differences were lower than 10% of the value found for the standard position. (DANTAS/STANFORD)

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Jaekel O, Reiss P. The influence of metal artifacts on the range of ion beams. Phys Med Biol 2007;52:635–644.

The influence of artifacts due to metal implants on the range of ion beams was investigated using a geometrically well-defined head and pelvic phantom together with inserts from steel, titanium, and tungsten. The ranges along various beam paths, including artifacts, were calculated from the treatment planning system and compared to known calculations for phantoms without any insert. In the head phantom, beams intersecting the streak artifacts led to errors around or below 1%, which was mainly due to a cancellation of various effects. Beams through the metal or close to it showed an underestimation of 3.5% of the range for tungsten. For the pelvic phantom, a large underestimation of the range was observed for a lateral path through the metal insert. In the case of tungsten and steel, range errors of −5% and −18% were observed, respectively. Such beam paths are typically used for pelvic tumors in radiotherapy with ion beams. For beams in the anterior-posterior direction through the inserts, overestimation of ion ranges of up to 3% for titanium and 8% for steel is expected, respectively. Beam paths outside the metal insert showed a large cancellation for the lateral beams (leading to errors of around 1%) and somewhat higher errors for anterior-posterior beams (around 3% for titanium and 6% for steel). The analysis of CT data of patients with gold dental implants as compared to patients with healthy teeth also showed a significant effect of the artifacts on the distribution of HU in the data, namely a redistribution of HU to higher and lower values as compared to patients with healthy teeth. The corresponding mean range variation was a 2.5% reduction in the data with artifacts as compared to the data without artifacts. It is concluded that beam paths through metal implants should generally be avoided in proton and ion therapy. In this case, the underestimation of ion range due to artifacts alone may amount to 3% for dental fillings and up to 5% and 18% for hip prostheses made of titanium and steel, respectively. It is important to note that the size of the metal inserts cannot be determined correctly from the images, so that a correction of the ranges in metal also leads to large uncertainties. Finally, it should be stressed that the stated relative deviations are valid only for the investigated phantoms and can only give a rough estimate of the size of range uncertainties that may appear in real patients. (JAEKEL/STANFORD)

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van Steenberghe D, Glauser R, Blomback U, et al. A computed tomographic scan-derived customized surgical template and fixed prosthesis for flapless surgery and immediate loading of implants in fully edentulous maxillae: A prospective multicenter study. Clin Implant Dent Relat Res 2005;7(suppl 1):S111–S120.

Based on 3-dimensional implant planning software for computed tomographic (CT) scan data, customized surgical templates and definitive dental prostheses can be designed to ensure high-precision transfer of implant treatment planning to the operative field and immediate rigid splinting of the implants, respectively. The aim of the present study was to *(1)* evaluate a concept including a treatment planning procedure based on CT scan images and a prefabricated fixed prosthetic reconstruction for immediate function in maxilla using a flapless surgical technique and (2) validate the universality of this concept in a prospective multicenter clinical study. Twenty-seven consecutive patients with edentulous maxillae were included. Treatments were performed according to the Teeth-in-an-Hour concept (Nobel Biocare, Goteborg, Sweden), which includes a CT scan–derived customized surgical template for flapless surgery and a prefabricated prosthetic suprastructure. All patients received their definitive prosthetic restoration immediately after implant placement, that is, both the surgery and the prosthesis insertion were completed within approximately 1 hour. In the 24 patients followed for 1 year, all prostheses and individual implants were recorded as stable. The present prospective multicenter study indicates that the prefabrication on the basis of models derived from 3-dimensional oral implant planning software of both surgical templates for flapless surgery and dental prostheses for immediate loading is a very reliable treatment option. It is evident that the same approach could be used for staged surgery and in partial edentulism. (van Steenberghe/Stanford)

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Di Giacomo GA, Cury PR, de Araujo NS, Sendyk WR, Sendyk CL. Clinical application of stereolithographic surgical guides for implant placement: Preliminary results. J Periodontol 2005;76:503–507.

The success of implant-supported restorations requires detailed treatment planning, which includes the construction of a surgical guide. Recently, computer-aided rapid prototyping has been developed to construct surgical guides in an attempt to improve the precision of implant placement. The aim of the present study was to evaluate the match between the positions and axes of the planned and placed implants when a stereolithographic surgical guide was employed. Six surgical guides used in 4 patients (3 women, 1 man; age range, 23 to 65 years old) were included in the study, and 21 implants were placed. A radiographic template was fabricated, and computer-assisted tomography (CT) was performed. The virtual implants were placed in the resulting 3-dimensional image. Using a stereolithographic machine, liquid polymer was injected and laser-cured according to the CT image data with the planned implants, generating 3 surgical guides with increasing tube diameters corresponding to each twist drill diameter (2.2, 3.2, and 4.0 mm), for each surgical area. During the implant operation, the surgical guide was placed on the jawbone and/or the teeth. After surgery, a new CT scan was obtained. Software was used to fuse the images of planned and placed implants, and the locations and axes were compared. On average, the match between the planned and the placed implant axes was within 7.25 ± 2.67 degrees; the differences in distance between the planned and placed positions were 1.45 ± 1.42 mm at the implant shoulder and 2.99 ± 1.77 mm at the implant apex. In all patients, a greater distance was found between the planned and placed positions at the implant apex than at the implant head. Clinical data suggest that computer-aided rapid prototyping of surgical guides may be useful in implant placement. However, the technique requires improvement to provide better stability of the guide during the surgery in cases of unilateral bone-supported and non–tooth-supported guides. Further clinical studies using greater number of patients are necessary to evaluate the impact of the stereolithographic surgical guide on implant therapy. (Giamcomo/Stanford)

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Mischkowski RA, Zinser MJ, Neugebauer J, Kubler AC, Zoller JE. Comparison of static and dynamic computer-assisted guidance methods in implantology. Int J Comput Dent 2006;9:23–35.

The planning of dental implant position and its transfer to the operation site can be considered one of the most important factors for the long-term success of implant-supported prosthetic and epithetic restorations. This study compareed computer-assisted fabricated surgical templates (the static method) with intraoperative image-guided navigation (the dynamic method) for transfer of 3-dimensional preoperative planning. For the static method, the systems Med3D, coDiagnostix/gonyX, and SimPlant were used. For the dynamic method, the systems RoboDent and VectorVision2 were applied. A total of 746 implants were placed between August 1999 and December 2005 in 206 patients. The static approach was used most frequently, accounting for 611 implants in 168 patients. The failure ratios within the first 6 months were 1.31% in the statically controlled insertion group compared to 2.96% in the dynamically controlled insertion group. Complications related to incorrect implant positioning have not been observed so far in either group. All computer-assisted methods included in this study were successfully applied in a clinical setting after a start-up period. The indications for application of computer-assisted methods in implantology are currently given in difficult anatomic situations. Due to uncomplicated handling and low resource demands, the static template technique can be recommended as the method of choice for the majority of all cases falling into this category. (Mischkowski/Stanford)

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