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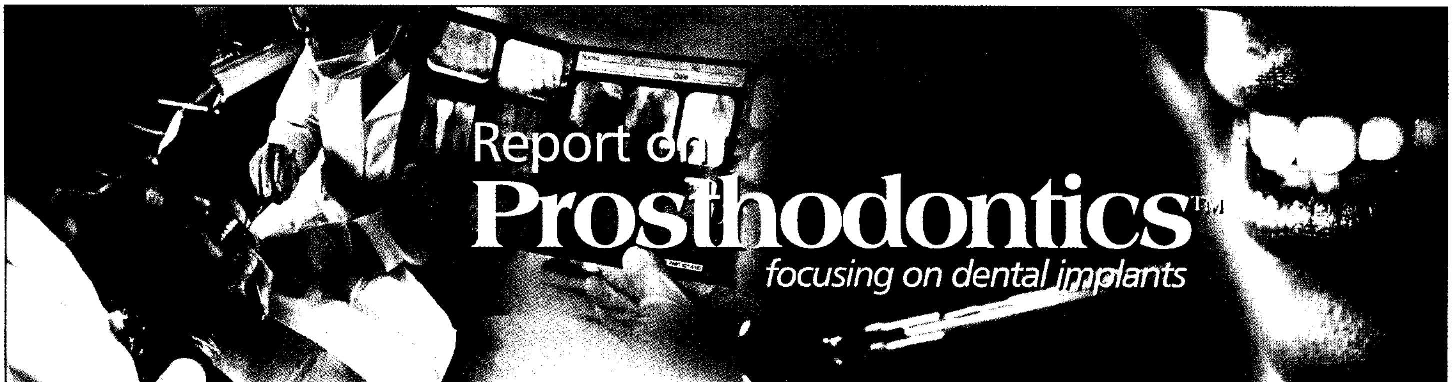

Computer-based Treatment Planning

Computed tomographic (CT) scanning has gained popularity for visualizing a patient's anatomy in order to determine the viability of implant placement. Over the past decade, software packages using computer-aided design (CAD) technologies have been developed that allow 3-dimensional (3-D) views. Early programs enhanced presurgical evaluation, but the limiting factor was their ability to transfer the presurgical plan to the surgical field; computer-aided manufacturing (CAM) technologies utilizing the data developed in the CAD software made that transfer possible. This issue of Report on Prosthodontics *reviews a series of articles related to advanced radiographic techniques and surgical-guide programs using CAD/CAM technologies.*

A Custom Template for Surgical Placement of Implants in the Maxilla

Inspired by earlier case-study reports of successful immediate implant loading using CAD/CAM custom surgical guides along with definitive prostheses developed from dental implant treatment-planning software, van Steenberghe et al from Catholic University Leuven, Belgium, studied the accuracy of transferring 3-D planning software. Following the system protocol, a spiral CT scan of the maxilla was performed on 2 cadaver specimens and 8 consecutive human patients and their radiographic templates. The templates were scanned with and without the patient or cadaver. The system studied in their research project, LITORIM (Leuven information technology-based oral rehabilitation by means of implants), is the precursor name to NobelGuide. The DICOM (Digital Imaging and Communications in Medicine) files were converted by the software for viewing, and the implant positions were planned.

Following the surgical/prosthetic procedure, new CT scans were performed for evaluation. The planned and achieved implant positions were evaluated based on an image volumetric registration technique. Each implant was compared with its

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planned position at the head and the tip of the implant. At the head of the implant, the mean deviation was 0.8 ± 0.3 mm, while the mean deviation at the tip of the implant was 0.9 ± 0.3 mm. In addition, the degree of variation between the planned site and the actual site was measured; the mean angular deviation was 1.8 ± 1.0° (Figure 1).

Of the 8 consecutive patients, 1 implant could not be used because of the deviation in its placement as a result of not using the guide sleeve during implant placement. The fit between the abutments of the immediately loaded prosthesis and the implants was verified using a postoperative orthopantomogram. A slight space was seen on 5 of the 61 implants, which the authors attributed to difficulties in visual control while tightening the abutments onto the implants.

Although no standard in terms of threshold of allowable variation has been determined, the amount of mean variation appears to be small. Keeping in mind that the sample size was limited in this study, the preliminary results were promising. Twelve months follow-up revealed that all implants in the 8 consecutive patients were successfully connected to prostheses and functioning well.

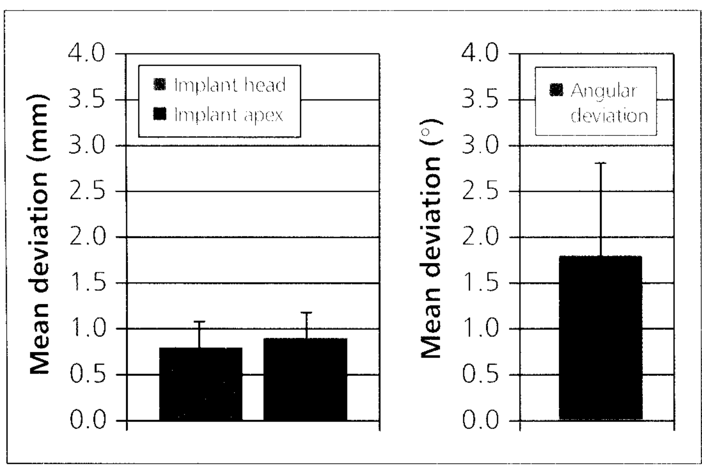

Figure 1. Mean deviation of implant position from the planned position.

van Steenberghe D, Naert I, Andersson M, et al. A custom template and definitive prosthesis allowing immediate implant loading in the maxilla: a clinical report. Int J Oral Maxillofac Implants *2002;17:663-670.*

Presurgical Planning with 3-D Cone-beam Imaging for Implants in the Partially Edentulous Jaw

Three-dimensional radiographic imaging and computer-based 3-D planning have evolved over time. Volumetric tomography has been developed to overcome limitations of conventional tomography. Its use for the partially edentulous patient population brings forth questions of whether the accuracy seen with the use of spiral CT scans for edentulous patients is transferred to cone-beam CT (CBCT) scans for the partially edentulous patient.

Van Assche et al from Catholic University Leuven, Belgium, conducted a cadaver study to evaluate ex vivo implant placement based on presurgical planning of 3-D CBCT images. Methacrylate resin radiographic templates were constructed with 6 gutta-percha markers at different levels in relation to the occlusal plane. Simulating the in vivo scanning process, the cadaver mandibles with the radiographic templates and the radiographic templates alone were scanned using CBCT. The DICOM files (CBCT radiographic images) were converted using Procera software to enable presurgical treatment planning.

Once the implant planning was completed, the computer data was sent via the Internet to the manufacturing facility for fabrication of the surgical guide. Twelve implants were placed in 4 cadavers using the surgical guides. A CBCT scan was then performed to evaluate the position of implant placement. The pre- and post-CBCT images were geometrically aligned by automated image registration using maximization of mutual information. Each anatomic location was mapped to its corresponding location.

The deviation at the coronal point of the implant ranged from 0.3–2.3 mm (mean, 1.1 mm), while the deviation at the apex of the implant ranged from 0.3–2.4 mm (mean, 1.2 mm). The mean angular deviation was 1.8°, with only 1 of the 12 implants having a deviation >2.5°; that implant deviated 4°. Deviations appeared to be affected by guide design. Guides that did not have support over the entire dental arch had larger deviations; guides that were supported by teeth bilateral to the implant position had smaller deviations than those lacking tooth support on 1 end or those that were only supported by the palate.

This study validates the use of CBCT in 3-D presurgical planning for implant placement and surgical-guide fabrication for the partially edentulous jaw. The evidence shows minimal to no variation in actual implant position as compared with the virtually planned implant position. In fact, the data for the partially edentulous patient was equal to, if not in some cases better than, the results reported by the same authors for the edentulous maxilla using spiral CT. It should be emphasized that a properly designed guide–rigid, stable, with maximum tooth support and anchor pins–results in better accuracy for implant placement.

Van Assche N, van Steenberghe D, Guerrero ME, et al. Accuracy of implant placement based on pre-surgical planning of three-dimensional cone-beam images: a pilot study. J Clin Periodontol *2007;34:816-821.*

Implant Placement Using a Stereolithographic Surgical Guide

Intuitively, one would surmise that a surgical guide developed from computer-based 3-D planning software using CT and CAD/CAM technologies would be more accurate than conventional surgical guides. Sarment et al from the University of Michigan, Ann Arbor, appear to be the first to verify the premise.

Five identical epoxy models of edentulous mandibles were used for this study. CBCT scanning of mandibular models was performed. Using Sim/Plant (Materialise Medical; Glen Burnie, Md.) planning software, surgical guides were fabricated for the placement of 5 implants on each side of the mandible. On the right side (control), a conventional surgical guide was used, and the channels were widened to allow for a 3.2-mm surgical drill. A stereolithographic guide (SurgiGuide; Materialise Medical) with incremental guiding tubes diameters was used for the left side (test).

Five surgeons participated in the study. Each surgeon placed 10 implants in their respective mandible, for a total of 50 implants. Following placement of the dental implants, CT scans were performed on the jaw models. These scans were compared with those from the planning position. Two

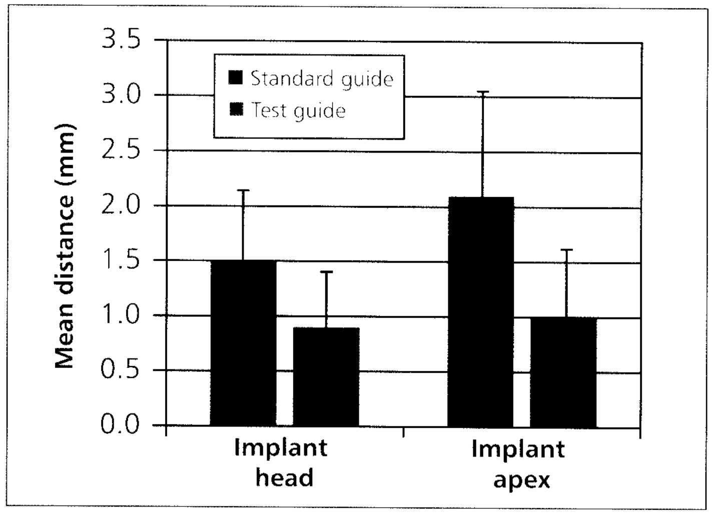

Figure 2. Overall mean distance and standard deviation between the center of the virtual implants and the center of the actual implants ($p < .001$).

areas were evaluated: the most coronal aspect of the implant and the apex. Angular variations between the virtual and the actual implant positions were calculated. The measurements were repeated by the same examiner on 2 separate days (interexaminer reliability: 85%, linear; 87%, angular) and the coordinates were averaged.

At the most coronal aspect of the implant, the standard guide produced an implant position that varied 1.5 ± 0.7 mm from the planned position, in contrast to the stereolithographic guide that varied 0.9 ± 0.5 mm. At the coronal aspect, the range in variation between surgeons was 1.0–1.8 mm with the standard guide and 0.7–1.2 mm with the SurgiGuide. At the apex of the implant, the standard guide produced an implant position that varied 2.1 ± 0.97 mm from the planned position; the stereolithographic guide varied 1.0 ± 0.6 mm (Figure 2).

The variations between surgeons at the apex of the implant ranged from 2.0–3.7 mm with the standard template to 0.7–1.6 mm with the SurgiGuide. Similar trends were seen in angular variation. The accuracy of the standard technique was 8.0 ± 4.5°, while with the stereolithographic guide the variation was 4.5 ± 2.0° (Figure 3). All the data showed statistically significant differences.

This study illustrates the different outcomes produced with the 2 types of surgical guides. Although the same planning software was used for both guides, there were clear differences in accuracy of execution based on the guide used.

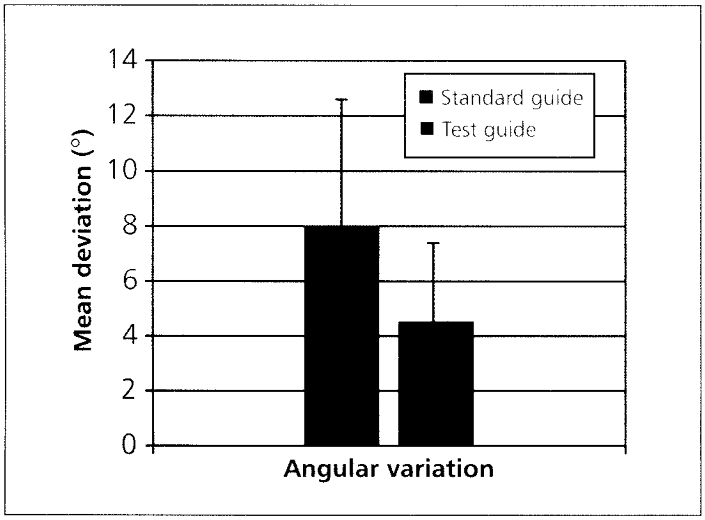

Figure 3. The accuracy of the standard guide vs the stereolithographic test guide.

Clearly, greater precision is achieved when computer-based planning is implemented with CAD/CAM technology to develop the surgical guide.

Sarment DP, Sukovic P, Clinthorne N. Accuracy of implant placement with a stereolithographic surgical guide. Int J Oral Maxillofac Implants *2003;18:571-577.*

Virtual Planning Using Cone-beam CT Data and Surgical-guide Imaging

Computer-assisted navigational tools to aid in transferring a plan to reality could prove to be a helpful instrument in our implant armamentarium. The key to such success is the accurate application of such devices. Although in vitro and limited in vivo studies, along with case reports, have suggested this to be true, long-term clinical studies are necessary to confirm the success of these methods. Nickenig and Eitner from Friedrich-Alexander-University Erlangen-Nuremberg, Germany, completed a study (102 patients; 250 implants) placing implants with the coDiagnostiX (IVS-Solutions, Germany) image-guided system.

CBCT images were made of patients wearing radiographic scanning templates with 3 titanium markers. The CBCT images were transferred to 3-D planning software to position the implant. The template was mounted into a special laboratory machine that drilled a 2- to 3-mm–diameter channel for each implant position as defined by the virtual planning coordinates. This template was then used for the surgical drill guide with small tube-in-tube sleeves for the different drill sizes.

The study assessed the fit of the surgical guide and handling problems, reliability of the surgical protocol and the actual implant position compared with the planned position using postoperative panoramic radiographs. A total of 98.4% of the surgical guides had no problems with fit or intraoperative handling. Four patients had a limited opening, which resulted in the need for heights of the guides to be reduced by 50%. In all but 8 patients the surgical guides were used; these patients required a change in protocol resulting in bone augmentation and delayed implant surgery.

The data from the comparison between the planned and actual implant position showed excellent outcomes. A total of 233 implants showed no discernible difference between preoperative and postoperative radiographs; however, 9 implants were not exactly parallel to the proposed position. No data were given regarding the amount or degree of deviation from the planned sites. It should be noted that there was no clinical significance to their positional changes. The results of this study are very promising and bring the profession one step closer to verifying the clinical reliability of the transfer of virtual implant planning to the clinical setting.

Nickenig H-J, Eitner S. Reliability of implant placement after virtual planning of implant positions using cone beam CT data and surgical (guide) templates. J Craniomaxillofac Surg *2007;35:207-211.*

In the Next Issue:

- **Immediate loading of implants in the edentulous mandible**
- **Indications for immediate loading of implants**
- **The Speed Master system for immediate loading of implants**
- **A long-term cohort study of immediately loading**

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