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Clinical Application of Stereolithographic Surgical Guides for Implant Placement: Preliminary Results

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**Background:** 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 is employed.

**Methods:** Six surgical guides used in four patients (three women, one man; age from 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 three 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 taken. Software was used to fuse the images of planned and placed implants, and the locations and axes were compared.

**Results:** On average, the match between the planned and the placed implant axes was within $7.25° ± 2.67°$; the differences in distance between the planned and placed positions at the implant shoulder were $1.45 ± 1.42$ mm, 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.

**Conclusions:** 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 real impact of the stereolithographic surgical guide on implant therapy. *J Periodontol 2005;76:503-507.*

**KEY WORDS**
Dental implantation; dental implants; patient care planning; surgery, computer-assisted; tomography, computer-assisted.

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Presurgical planning is essential to obtain esthetic and functional implants, and a variety of techniques is presently available.1 In cases of compromised host bone or increased esthetic demand, more detailed information is required, which in turn, justifies the use of more elaborate planning techniques. Multiplanar computerized tomography (CT) is the most frequently used aid in treatment planning, and various software programs enable precise, preoperative evaluation of the patient’s 3-dimensional anatomy for implant placement. Several methods have been proposed to transfer the planning stage to surgery. Computer-aided rapid prototyping of surgical guides apparently transfers the 3-dimensional image accurately to the surgical site, translating a sophisticated plan to the surgical field.2-6 However, no definitive evidence is available. Sarment et al. compared the traditional surgical guide with the stereolithographic surgical guide in vitro, and reported that implant placement was improved by using a stereolithographic surgical guide.5 These authors also demonstrated in two clinical cases that the use of a stereolithographic surgical guide allowed precise translation of the treatment plan directly to the surgical field.3 van Steenberghe et al. reported a nearly perfect match between the positions and axes of the planned and placed implants, when a stereolithographic surgical template was used in two cadavers and eight patients (15 implants).4 Tardieu et al. presented
a case of implant placement using a drill guide created by stereolithography; however, they did not show the differences between planned and final implant positions.6

The aim of the present study was to evaluate the match between the positions and axes of placed and planned implants using a stereolithographic surgical guide.

MATERIALS AND METHODS

The study protocol was approved by the Institutional Ethics Committee of the University of Santo Amaro. Informed consent was obtained from all subjects.

Surgeries were performed from September 2002 to February 2003. Four healthy, non-smoking patients requiring dental implants were enrolled. Six surgical guides in the four patients (three women, one man; aged from 23 to 65 years old) were included in the study, and 21 implants were placed.

Following periodontal therapy, diagnostic casts and waxups were made. The original casts with diagnostic waxups were duplicated. A rigid, clear template (1.0 mm) was fabricated over the duplicated cast, using a vacuum former device,‡ to serve as a radiographic template to be worn during the CT scan (Fig. 1). In the edentulous areas, the templates were coated with a mixture composed of 10% high-density barium in 90% varnish. The template was then inserted into the patient’s mouth, and computer-assisted tomography§ was initiated. Overlapping sections, 1.0 mm in thickness, were obtained. On average, 40 to 50 sections were required for mandibles and maxilla. Both first and second scans were taken by the same radiologist. The axial plane was adjusted parallel to the plane of occlusion, with the Gantry tilt at 0 degrees. The CT scan was taken without interarch contact, biting on a piece of wood, and the patient was immobilized during the entire process.6

The resulting CT images were converted to a DICOM image (digital imaging and communications in medicine) and sent to the manufacturer¶ for data conversion into a standard triangle language file (*.stl file), whereby a 3-D model consisting of triangles was obtained. The resulting data were forwarded via e-mail to us. One examiner placed the virtual implants in the resulting 3-dimensional model using a software program.¶ The potential bone sites for implant placement, and implant lengths and widths were planned. The images were returned to the manufacturer for surgical guide fabrication.

Using a stereolithographic machine, liquid polymer was injected and laser-cured according to the CT image data. This procedure generated a model and three surgical guides of increasing tube diameter (2.2, 3.2, and 4.0 mm, respectively) for each surgical area. The stainless steel guide tubes were inserted at the locations and axes of the planned implant.

All surgeries were performed by the same clinician under local-regional anesthesia, with appropriate aseptic and sterile procedures. During the operation, the surgical guides were placed on the jawbone (bone-supported guides: patient 2, surgical guides 2 and 3; patient 4, guides 6 and 7); on the teeth (tooth-supported guides: patient 3, guides 4 and 5); or on both bone- and tooth-supported guides (patient 1, guide 1). The guides were numbered according to Table 1. Surgery consisted of the initial incisions at the ridge crest, vertical releasing incisions, and mucoperiosteal flaps. The first guide was positioned and osteotomies were prepared using 2.0 mm round burs and 2.0 mm rotating drills. The first guide was removed, the second template was placed, and the 3.0 mm drills were used. When necessary, the third guide was used. The template was removed and the implants placed.# The flaps were adapted and sutured.

After surgery, new CT scans were taken. Software was used to fuse the images of the planned and placed implants, and the locations and axes were compared (Fig. 2). The first and second scans were aligned observing the superposition of anatomic markers and the edentulous areas of the template, which had been coated with 10% high-density barium. For each virtual and real implant, two points were located (x, y, and z coordinates were recorded) on their long axes, i.e., the shoulder point (center of the most coronal portion of

‡ Vacuforme, BioArte Equipamentos Odontológicos Ltda, São Paulo, SP, Brazil.
§ HiSeed/CTi Advanced, General Electric, Milwaukee, WI.
¶ CSI Materialise, Ann Arbor, MI.
SimPlant, CSI Materialise.
# Osseotite, 3I, Palm Beach Gardens, FL.
the implants) and the apex point (center of the implant apex). The distances between the centers of the virtual and final implants were calculated. The angles formed between the virtual and the placed implants were also calculated mathematically.

RESULTS
Table 1 lists the differences between the planned and achieved implant positions and axes.

The match between the planned and achieved implant axes was within 7.25 ± 2.67 degrees; average differences in distance between the planned and achieved positions at the implant shoulder were 1.45 ± 1.42 mm, and at the implant apex, 2.99 ± 1.77 mm. A greater distance between the planned and achieved positions at the implant apex than at the implant head was encountered in all patients.

Patient 3 exhibited the greatest differences between the final implant axes and that planned on the right side of the maxilla. The surgical guide fitted perfectly on tooth #16, but did not fit perfectly on the distal portion of tooth #13, resulting in a considerable difference between the planned and actual positions. On the left side of the maxilla, the surgical guide fitted perfectly on teeth #23 and #26, and provided a stable position, resulting in the lowest differences in axes and apex positions. For patient 1, the surgical guide was both tooth- and bone-supported, and also presented stability during surgery, which resulted in small differences in axes between the planned and obtained implant positions.

Patient 4 presented the greatest difference between the planned and final apex and shoulder positions on the right side of the maxilla, and also a considerable difference between the planned and final axes. Both the left and right surgical guides were bone-supported, and it was not possible to obtain a stable fit during surgery, which explains the difference between the planned and actual positions. According to the manufacturer, it was not possible to make a tooth-supported guide due to an acrylic prosthesis, which resulted in an unsuitable image. The surgical guide for patient 2 was also bone-supported but extended to both right and left side of the mandible, where it provided considerable stability, resulting in a slight difference between the planned and final implant positions and axes.

DISCUSSION
Computerized tomography is a useful tool in the rehabilitation of complex implant cases when anatomical limitations, reduced bone dimensions, and compromised bone density are present. The use of CT, compared to 2-dimensional cross-sectioning, improves the correlation between the planning phase and actual implant placement. However, only implant position is reproducible; implant lengths and widths are often modified during surgery. The advent of coordinated computer-aided manufacturing (CAM) of anatomic models and surgical templates based on computer-aided design (CAD) images has permitted the direct transfer of information gathered during planning to the surgical phase of implant placement. The incorporation of CAD and CAM for implant planning and placement offers several advantages, including 3-dimensional evaluation of the patient's anatomy and fabrication of both anatomical site models and bone-supported, surgical templates.

Rapid prototyping using stereolithographic modeling is recognized in the manufacturing industry as a fast and economical CAM method used to obtain prototypes. In dentistry, this technique has been used to aid in the preoperative preparation of reparative strategies in large osseous lesions, diagnosis of sinus elevations, and the design of soft-tissue facial prostheses.
It has been suggested that CAD and CAM using commercial software and hardware may improve the accuracy of planning and placing dental implants. However, there is no definitive evidence and the technique involves additional costs.

In the present study, the differences noted between planned and final implant positions and axes may have resulted from micro-movements of the surgical guide during surgery, despite the care taken, or possible differences in the positions of the first and second surgical guides. On average, the match between planned and the achieved implant axes was within $7.25 \pm 2.67$ degrees. The differences in distance between the planned and achieved positions at the implant shoulder was $1.45 \pm 1.42$ mm, and at the implant apex was $2.99 \pm 1.77$ mm. For all surgical guides, there was a greater distance between the planned and the actual positions at the implant apex than at the implant head. We did not use screws to stabilize the surgical guide. It is possible that the use of stabilizing screws may decrease differences between planned and placed implants in cases of bone-supported guide extending only to one side of the mandible/maxillae.

Besimo et al. compared planning to placement of implants using conventional surgical guides. The deviation between the positions of the apex of the proposed implants in paraxial CT reformats and on the corresponding study cast was measured in 77 prospective sites in five maxillae and nine mandibles. The transfer error was $0.6 \pm 0.4$ mm in the maxilla and $0.3 \pm 0.4$ mm in the mandible. The transfer errors detected in that investigation were smaller than those in our study, and such precision suggests that further refinement of the surgical guides might not be necessary. However, Sarment et al. found a statistically significant improvement in all measurements when stereolithographic surgical guides are used compared to conventional guides, and suggested that the clinical significance of this result may be relevant when multiple parallel distant implants are placed, and where the degree of accuracy is critical to obtain a single prosthetic path of insertion. These authors also reported an average distance between the planned implant and the actual osteotomy greater than noted by Besimo et al. for both conventional and stereolithographic surgical guides: $1.5$ mm at the entrance and $2.1$ mm at the apex when the control guide was used; and $0.9$ mm and $1.0$ mm when the stereolithographic surgical guide was used. Unlike our study, the implants were placed in five epoxy edentulous mandibles. Like Sarment et al., van Steenberghe et al. reported maximum distances in two cadaver specimens of $1.1$ mm between planned and actual locations in the longitudinal direction of the implants. Their differences between planned and achieved results are lower than ours. In the present study, the difference between axes was also greater ($7.25$ degrees) than that reported in the literature (1.8 degrees in two cadaver specimens, and $8 \pm 2$ degrees in epoxy mandibles). Evidently, it is simple to control any stage of implant surgery in such experimental models. In the clinical reports, the distances and axes were not provided.

Using the system as we did, Tardieu et al. presented a case of implant placement using a drill guide created by stereolithography. They suggested that the scannographic template could be designed so that it can be transformed into a temporary fixed prosthesis for immediate loading.

In conclusion, computer-aided rapid prototyping of surgical guides may be useful in implant placement. However, the technique requires improvement to provide a better stability of the guide during surgery, in cases of unilateral bone-supported and non-tooth-supported guides, and cost effectiveness also should be taken into consideration.

Further clinical studies employing a greater number of patients should be performed to evaluate the real impact of the stereolithographic surgical guide on implant therapy.

REFERENCES


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