Accuracy of Implant Placement with a Stereolithographic Surgical Guide

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Purpose: *Placement of dental implants requires precise planning that accounts for anatomic limitations and restorative goals. Diagnosis can be made with the assistance of computerized tomographic (CT) scanning, but transfer of planning to the surgical field is limited. Recently, novel CAD/CAM techniques such as stereolithographic rapid prototyping have been developed to build surgical guides in an attempt to improve precision of implant placement. However, comparison of these advanced techniques to traditional surgical guides has not been performed. The goal of this study was to compare the accuracy of a conventional surgical guide to that of a stereolithographic surgical guide.* ***Materials and Methods:*** *CT scanning of epoxy edentulous mandibles was performed using a cone beam CT scanner with high isotropic spatial resolution, while planning for 5 implants on each side of the jaw was performed using a commercially available software package. Five surgeons performed osteotomies on a jaw identical to the initial model; on the right side a conventional surgical guide (control side) was used, and on the left side a stereolithographic guide was used (test side). Each jaw was then CT scanned, and a registration method was applied to match it to the initial planning. Measurements included distances between planned implants and actual osteotomies.* ***Results:*** *The average distance between the planned implant and the actual osteotomy was 1.5 mm at the entrance and 2.1 mm at the apex when the control guide was used. The same measurements were significantly reduced to 0.9 mm and 1.0 mm when the test guide was used. Variations were also reduced with the test guide, within surgeons and between surgeons.* ***Discussion:*** *Surgical guidance for implant placement relieves the clinician from multiple perioperative decisions. Precise implant placement is under investigation using sophisticated guidance methods, including CAD/CAM templates.* ***Conclusion:*** *Within the limits of this study, implant placement was improved by using a stereolithographic surgical guide.* (INT J ORAL MAXILLOFAC IMPLANTS 2003;18:571–577)

Key words: *computed tomography, computer-aided design, dental implants, stereolithography, surgical templates*

Although osseointegration of dental implants is a predictable consequence of surgical placement,[1,2] anatomic limitations as well as restorative demands encourage the surgeon to gain precision in planning and surgical positioning of implants. In addition, advances in osseous regenerative techniques have broadened the spectrum of potential implant candidates. For diagnosis, computerized tomographic (CT) scanning is a precise, noninvasive surveying technique.[3–7] Visualization of CT scan images by the clinician can be achieved using printed films or computer software packages,[8,9] which allow for 3-dimensional (3D) viewing using computer-aided design (CAD) technology.[10,11] When coupled with scannographic templates worn at the scanning visit, visualization of the restorative plan also improves presurgical evaluation.[12–15] In addition to visualization and other diagnostic tools such as the evaluation of bone density,[16] these software programs allow for placement of virtual implants to further assist the surgeon in foreseeing positioning and size of implants prior to surgery.[17,18] However, transfer of a sophisticated plan to the surgical field remains difficult.

To overcome this issue, several novel approaches have been developed. One of them utilizes a computer-aided manufacturing (CAM) technique to generate osseous-supported surgical guides as well as anatomic models (SurgiGuide; Materialise Medical,

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Figs 1a to 1d *Scanning and planning for implant placement.*

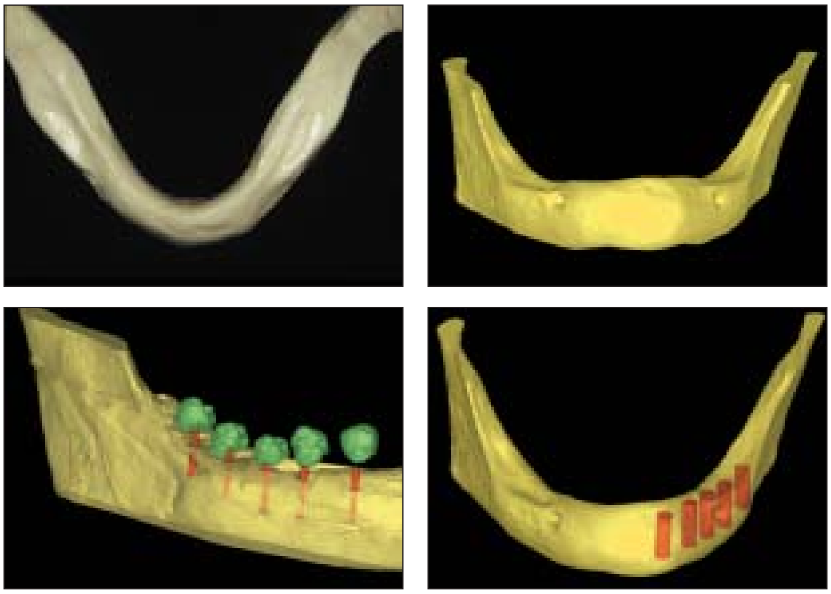


Fig 1a *(Left)* An epoxy jaw was CT scanned.

Fig 1b *(Right)* After processing of CT files, 3D rendering was made possible using software.

Fig 1c *(Left)* The radiopaque scannographic template was assigned a distinct color for better visualization. Planning was performed by placing virtual implants *(red cylinders)* on the right side where a standard surgical guide was to be used.

Fig 1d *(Right)* Virtual implants were placed on the left side where the test guide was to be used.

Glen Burnie, MD). Briefly, a transfer of the CT scan computer files and the surgeon's implant planning is utilized to design the surgical guides with computer software. Three-dimensional acrylic resin models and surgical guides that can fit intimately with the osseous surface are then processed; a computer-guided laser beam polymerizes a photosensitive liquid acrylic through a series of layers (stereolithography). Once hardened, the acrylic surgical guides contain spaces for stainless steel drill-guiding tubes. The metal cylinders are then forced into the spaces, and the guides are ready for clinical use.[15] Although this and other methods are available clinically, few attempts have been made to evaluate the precision of surgical placement as compared with planning and placement utilizing traditional laboratory-processed surgical guides. The purpose of this experiment was to measure the divergence between planned implants and actual surgical placement, using a simulated clinical scenario, and comparing this new CAD/CAM surgical guide with a conventionally produced guide.

MATERIALS AND METHODS

Five identical epoxy edentulous mandibles were obtained (Models Plus, Kingsford Heights, IN). A scannographic template was fabricated for the right side of a jaw only by setting 5 barium sulfate–containing acrylic premolars, at a distance from each other, on a custom tray material (Triad; Dentsply, York, PA). Two-millimeter channels were created in the long-axis of each tooth. The jaw model and its scannographic template were scanned using a prototype of the MiniCAT cone-beam CT scanner (Xoran Technologies, Ann Arbor, MI), which has high isotropic spatial resolution. Reconstructed voxel size was set to $400 \times 400 \times 400$ μm^3. Scanning files were transferred and segmentation was performed using software (Mimics; Materialise Technical, Ann Arbor, MI) to separate the teeth, the model, and the surrounding space. Then, one examiner (DS) planned the placement of 10 dental implants using software (Sim/Plant; Materialise Medical). On the side containing the scannographic template, implants were placed so that the virtual restorative post would be in the long axis of each tooth, as detected by the radiolucent space visible on the CT scan. After planning of this side, spaces were widened to approximately 3.2 mm to allow passage of the surgical drills.

On the left side of the jaw, where no scannographic template was present, 5 parallel implants were placed on the screen to simulate a similar clinical scenario. Planning of this side was submitted for fabrication of stereolithographic surgical guides (Figs 1a to 1d).

Therefore, 2 surgical guidance techniques were compared:

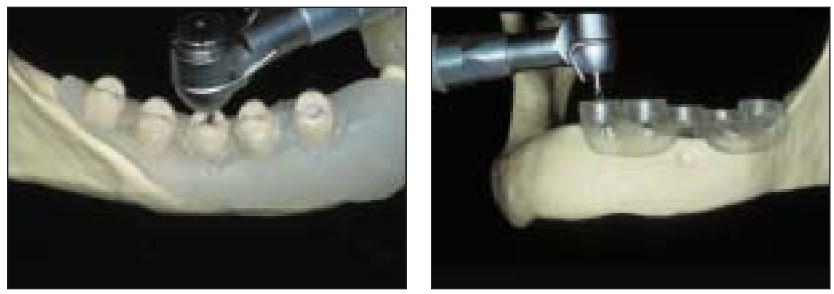
- Control side (right side): A standard surgical guide modified from the scannographic template was prepared by enlarging the axis holes made previously.
- Test side (left side): Stereolithographic guides (SurgiGuide) with incremental guiding tube diameters were fabricated.

Figs 2a to 2d *Osteotomies for control and test guides.*

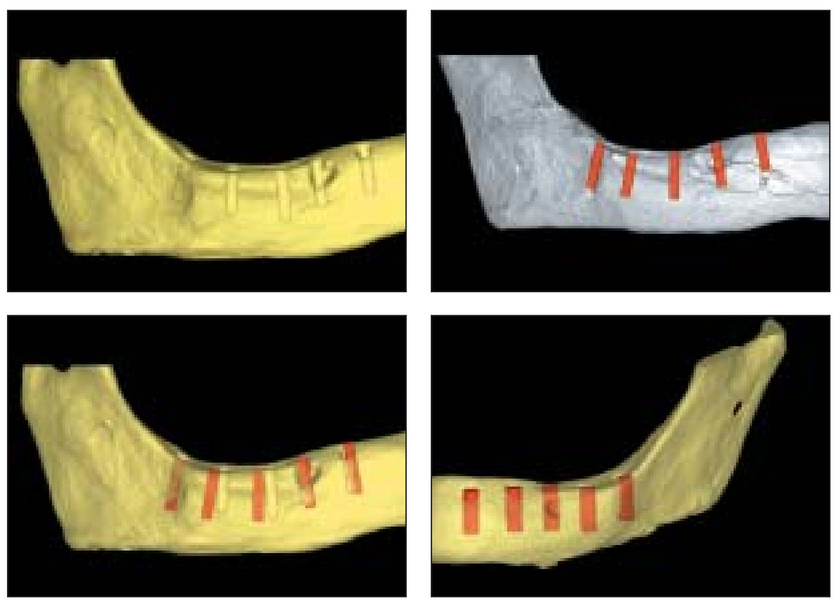
Fig 2a *(Left)* After scanning and planning, the computer files were submitted for stereolithographic fabrication of surgical guides with incremental guiding tubes. The jaw was also processed for visualization of the osseous topography.

Fig 2b *(Right)* The surgical guides fit precisely on the model.

Figs 2c and 2d Osteotomies were performed using *(left)* a standard guide on the right side and *(right)* the test guides on the left side.



Figs 3a to 3d Matching of experimental jaws with the planning jaw. *(Top left)* Each jaw was CT scanned after osteotomies were performed. *(Top right)* Implant planning was matched to the "postsurgical" result on the *(bottom left)* control and *(bottom right)* test sides using registration software.



Five experienced surgeons (periodontists regularly placing implants but without experience using the new guides) volunteered independently to perform osteotomies on the artificial jaws. They were given access to the implant planning by viewing the computer software showing the CT sections, the 3D reconstructions, and the virtual implants. Surgeons were able to go back to these plans at all times. They were given a jaw model and templates, as well as a set of drills (Nobel Biocare USA, Yorba Linda, CA), a handpiece, and an implant unit (Implant Innovations, Palm Beach Gardens, FL). The control side was prepared first, followed by the test side. Surgeons were asked to prepare 10-mm-long implant sites (Figs 2a to 2d).

After the "surgical" step, the jaws were returned for CT scanning. For each jaw, scanning was compared to the planning that was performed using a registration method (Figs 3a to 3d). Briefly, the software (Analyze version 4.0; AnalyzeDirect, Lenexa, KS) utilizes a mutual information algorithm to minimize differences in neighboring pixels. Registered jaws were then imported to the visualization software (Sim/Plant). For each osteotomy and corresponding virtual implant, 2 points were located (coordinates x,y,z were recorded) on their long axis:

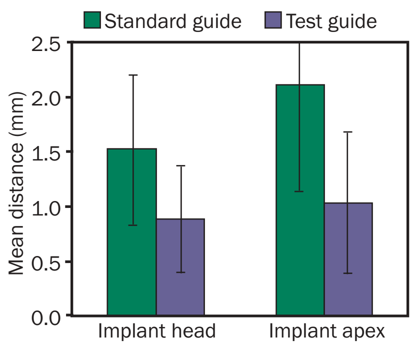


Fig 4 Overall mean distance and SD between the center of the "virtual" implants and the center of the actual osteotomies ($P < .001$).

the entrance points (center of the most coronal portion of the osteotomy and the virtual implants) and the apex point (center of the osteotomy 10 mm apical to the entrance point and center of the virtual implant apex). These measurements were repeated twice on separate days by the same examiner, and coordinates were averaged. The distance between centers was calculated. In addition, angles formed between the "virtual" implants and the corresponding osteotomy were calculated mathematically.

Statistical analysis was carried out, and standardization of measurements was established by calculating interexaminer correlation. Comparisons between groups were performed using 2-tailed *t* tests.

RESULTS

Interexaminer reliability was evaluated using repeated measurements of implant length and angles. Measurements were 85% and 87% reliable in obtaining the same length within 0.3 mm or the same angle within 3 degrees, respectively.

Overall placement of implants compared to planning was analyzed. When the control surgical guide was used, the average center of the osteotomy was 1.5 ± 0.7 mm (mean ± SD) away from the center of the planned implant at the coronal end and 2.1 ± 0.97 mm at the apex. In comparison, when the test appliance was used, this distance was 0.9 ± 0.5 mm at the implant head and 1.0 ± 0.6 mm at the apex (Fig 4). The difference was statistically significant ($P < .001$). Average variation between surgeons showed that the coronal center of the actual implant site could be as much as 1.8 mm away from the center of the virtual implant and as little as 1 mm when using the control guide. In contrast, the maximum and minimum distances were 1.2 mm and 0.7 mm, respectively, when using the test appliance. Standard deviations varied from 0.3 to 0.9 mm with the control guide and from 0.3 to 0.65 mm with the test guide (Fig 5). Similar average measurements were recorded for each surgeon at the apex of the implants. When surgeons used the standard template, distances varied from 2 to 3.7 mm, with standard deviations from 0.4 to 1.4 mm. The use of the test guide yielded results varying from 0.7 to 1.6 mm, with standard deviations from 0.4 to 0.7 mm (Fig 6).

With respect to measurement of the angle formed between the planned implant and the actual implant preparation, the standard technique allowed for an accuracy of 8 ± 4.5 degrees (mean ± SD) and the test method achieved an accuracy of 4.5 ± 2 degrees. This difference was statistically significant ($P < .001$). Average variation between surgeons was 6.8 to 8.7 degrees (SD, 3.3 to 5.6 degrees) with the control guide, versus angle variations from 3.5 to 5.4 degrees (SD, 1.4 to 2.3 degrees) when the test guide was utilized (Fig 7).

DISCUSSION

Multiple studies have demonstrated the value of CT imaging for diagnosis, planning, and placement of dental implants,[19] as compared to linear tomography or other 2D imaging.[3,5,20,21] CT views are useful for detection of anatomic limitations[22] as well as potential implant sites, but precise planning is often modified during surgery, especially with regard to location and implant sizes.[23] In recent years, commercial software packages have been developed to assist planning by providing viewing of CT sections and 3D reformatted images of the osseous surface on computer screens.[9,11,24,25] In this report, one of the commercially available software programs was used to visualize CT scanning of an edentulous mandible, and multiple "virtual implants" were also positioned prior to actual placement (Figs 1a to 1d).

When a CT scanning analysis is prescribed, it is recommended that a scannographic template be provided.[26] This acrylic appliance is a copy of the preprosthetic waxup, where diagnostic teeth are rendered radiopaque. A 30% barium sulfate/acrylic mix was used to process teeth and clear out their long axis. This method is in contrast to surface covering only, where the long axis of teeth may be more difficult to determine.[13,15]

Use of surgical guides has been described for visualizing the restorative plan during implant surgery and for outlining the ideal implant axis. Processing methods also utilize acrylic resin templates duplicating the diagnostic waxup and may include metallic

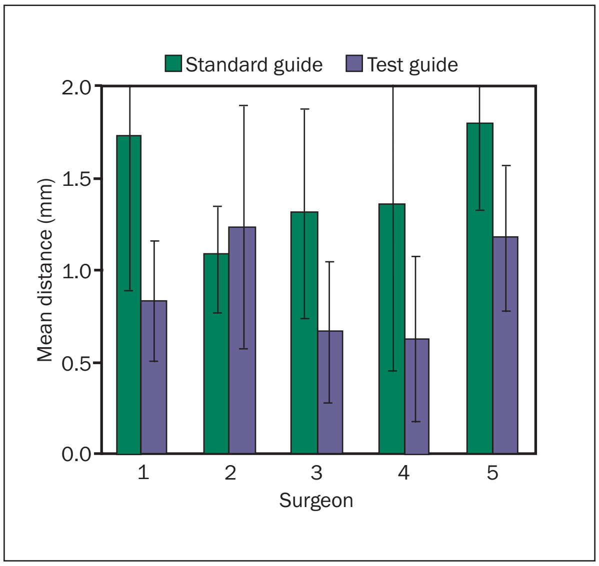


Fig 5 Mean distance and SD between the center of the "virtual" implants and the center of the actual osteotomies at the implant head for each surgeon.

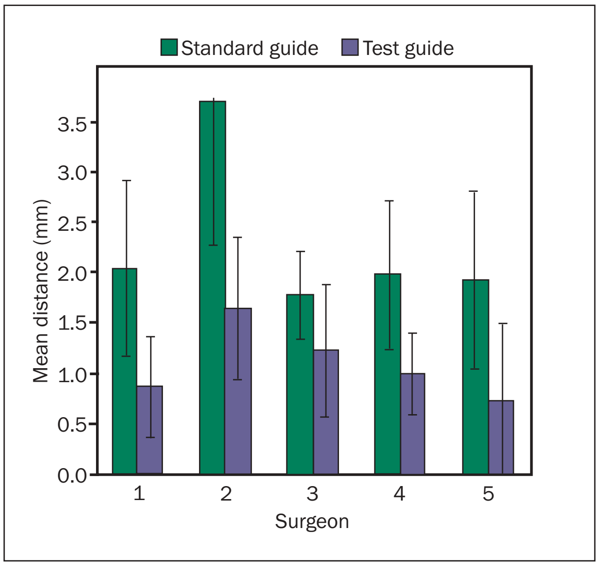


Fig 6 Mean distance and SD between the center of the "virtual" implant apex and the center of the actual osteotomy at 10 mm for each surgeon.

tubes for better guidance.[27,28] To improve control in the present study, the scannographic template was modified to provide for surgical guidance by enlarging cylinders in the long axis of the teeth.

Accuracy of traditional methods has rarely been assessed, but Naitoh and coworkers suggested that angulation diverges by 5 degrees on average when utilizing a template similar to the control in a clinical setting.[29] In a similar attempt to compare planning to placement, Besimo and associates[27] utilized a modified scannographic template for surgical guidance. Placement was evaluated by measurements on the casts of more than 70 clinical cases, and the implant apex was found to be between 0.3 to 0.6 mm on average from planning.[27] Such precision would suggest that further refinement of surgical guides may not be necessary. In the present study, it was possible to obtain similar results with the control guide.

Recently, several methods have been proposed to transfer planning to surgery. One of them, rapid prototyping using stereolithographic modeling, was used in this study and is known in the engineering industry as a fast, economical CAM method to obtain prototypes.[30,31] Its application to the medical field has allowed for visualization of large osseous lesions and preoperative preparation of reparative strategies.[32,33] Santler and colleagues, reporting on more than 300 trauma and cancer cases, demonstrated the advantage of 3D models in preparing for large surgical reconstructions.[34] Use of an anatomic model has also been suggested for diagnosis of sinus elevations,[35] preparation of periosteal implants,[36,37]

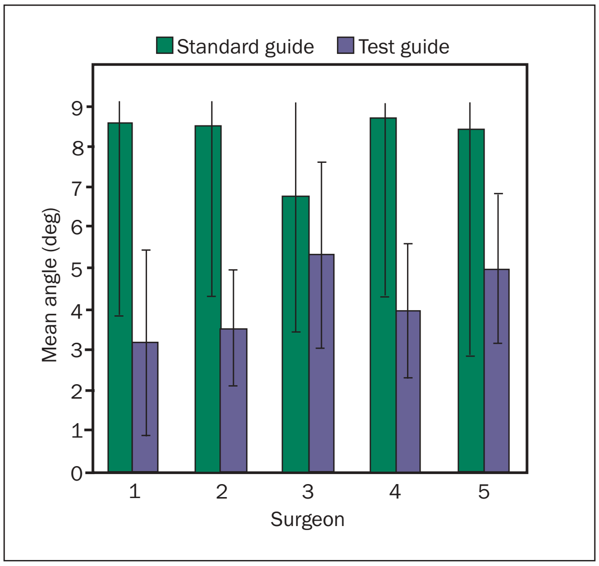


Fig 7 Mean angle formed between the "virtual" implants and the osteotomies for each surgeon.

and design of soft tissue facial prostheses.[38] Choi and associates evaluated the accuracy of these models by making linear measurements of multiple models and found that it was in the range of 0.5 mm.[39] Erickson and coworkers[40] surveyed surgeons who used custom anatomic models for diagnosis of surgical reconstruction and fabrication of custom implants. They found that a majority of clinicians had changed their surgical approach and gained surgical time when using these models.[40]

More recently, osseous-borne surgical guides were introduced for dental implant placement utilizing stereolithographic processing.[15,41] This commercially available method (SurgiGuide) does not necessitate any particular preparation prior to CT scanning. This technique is similar to another marketed modern implant guidance method in which metallic landmarks are positioned on a tooth-supported scannographic template. After CT scanning and planning, precise repositioning of the model to a milling machine can be achieved via the metallic reference points to position precise guiding tubes.[42,43] Although these 2 techniques may yield similar results, a comparison has not been performed.

Other innovative robotic technology developed for medical use is being applied to dental implant placement. Generally, it requires a real-time registration method to position the patient with the CT scan during the procedure. This is accomplished by placing reference markers on the patient's skin or on a scannographic template prior to scanning. Registration, which consists of matching "before" and "after" images, can be as precise as 1 mm or less when utilized during surgery.[44] Then, the surgeon's handpiece is positioned in space by means of infrared cameras or direct sensors. For instance, Wanschitz and coworkers[45] tested an extraoral optical tracking system via light-emitted diodes, using a similar study method to the one described in the present study. They reported an overall deviation of 0.96 ± 0.72 mm (mean ± SD) (0.5 mm at the implant head and 1.4 mm at the apex).[45] These results are similar to those of the present authors (0.9 ± 0.5 mm at the implant head and 1.0 ± 0.6 mm at the apex). This type of technology may have future dental applications, but further developments as well as examination of cost effectiveness are necessary.

A statistically significant improvement was found in all measurements when the stereolithographic surgical guides were used. More importantly, variations from the mean were also reduced. The clinical significance of these results may be relevant in situations such as when multiple parallel distant implants are placed, and where the degree of accuracy is critical to obtain a single prosthetic path of insertion. Reangulation or replacement of removable wearing parts could be reduced by the use of more accurate surgical implant placement.[46,47] In addition, modifications of prosthetically driven implant positioning based upon anatomic limitations are common after the CT scan is obtained. In such cases, the scannographic template can no longer be utilized as an accurate surgical guide, since restorative landmarks must be altered. In contrast, the CAD/CAM guides remain valid. Finally, an osseous-borne traditional guide was used. In a clinical setting, this is not possible, and stability of the guide is only feasible when natural teeth are present. In a large edentulous area or completely edentulous jaw, the stereolithographic guide is advantageous since it is osseous-supported.

The technology described in this article requires the clinician to possess and be knowledgeable about specialized software for diagnosis and planning. Versus traditional guide fabrication, CAD/CAM processing also involves additional costs. Therefore, its use is intended for patients in whom simultaneous placement of multiple implants and complex restorations make additional planning and expenses necessary.

CONCLUSION

Within the limits of this preclinical study, it can be concluded that the new surgical guides allow for improved implant placement. To the authors' knowledge, this is the first attempt to compare a traditional surgical guidance method to a CAD/CAM technology; however, further studies are necessary to validate its clinical use.

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