Precision of Flapless Implant Placement Using Real-Time Surgical Navigation: A Case Series

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Purpose: *To demonstrate the predictability of flapless surgery using navigation surgery.* ***Materials and Methods:*** *Computer-generated preoperative implant planning was compared to actual placement by CT (computerized tomography) scanning of patients before and after surgery. Once pre- and postoperative coordinates of virtual implants were obtained, linear distances and angles were calculated. Coronal and apical errors consisted of the shortest distance from the preoperative planning to the postoperative overlay.* ***Results:*** *Fourteen implants were placed in 6 patients who received CT scans before and after implant placement. Preoperative implant planning using software was compared to actual placement. The average discrepancy of the head of the implant was 0.89 mm ± 0.53 SD (range, 0.32 to 1.96). The average discrepancy of the apex of the implant was 0.96 mm ± 0.50 SD (range, 0.25 to 1.99). The average angle discrepancy and standard deviation were 3.78 degrees ± 2.76 SD (range, 0.60 to 9.87).* ***Conclusion:*** *Optical computerized navigation is vulnerable to technological and technical errors. Yet, the present case series suggests that less than 1 mm of mean linear deviation and less than 4 degrees of angular deviation might be attainable.* INT J ORAL MAXILLOFAC IMPLANTS 2008;23: 1123–1127

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Surgical placement of dental implants is a well-documented treatment for edentulism. Treatment success rates are high and postoperative complications relatively modest. Further enhancements in treatment modalities have included immediate loading and placement without flap elevation to increase patient comfort and acceptance.

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Flapless surgery has the potential to reduce postoperative discomfort.[1] However, the absence of visualization of the residual crest is a limiting factor because of possible placement outside of the bony envelope. The loss of bone width cannot be determined on a 2-dimensional traditional radiograph and can be difficult to evaluate clinically.

Computerized tomography (CT) scanning allows for a precise presurgical visualization of osseous contours. Also, software can render CT data and implant simulation can be performed, facilitating treatment planning, as well as implant selection. To transfer a simulated implant position to the surgical field, guidance and navigation methods have been developed.[2]

Surgical guidance utilizes CAD/CAM technology to generate guides that incorporate drilling housings for precise placement of implants according to preoperative plans. A few systems are available that allow fabrication of a computer-generated surgical guide.[3]

During the planning phase, a CT scan is obtained with a radiographic template in place; the surgeon performs implant-planning with dedicated software. Once implant selection and positioning have been determined, the system generates a surgical guide with incorporated drill housing, also known as a stereolithographic guide.

In contrast, navigation is the surgical placement of implants using a real-time computer-guided system based on information generated from a CT, patient positioning, and the handpiece's location.[4–8]

Computer-generated surgical guidance and navigation differ in that navigation allows visual verification on a computer screen of the drill's position animated onto the cross section of the surgical site in real time. Another difference is that modifications can be made at any time. In contrast, with a CAD/CAM surgical guide, changes to planning require refabrication of the surgical guide. However, a limitation of computerized navigation is that osteotomies are performed freehand and have potential for divergence resulting from operator error.

Although there is some initial precision data for CAD/CAM guidance,[4,5] there is little documentation of surgical navigation precision. Furthermore, preliminary laboratory studies cannot account for many important factors such as errors in CT acquisition due to patient movement, repositioning of reference guides at surgery, and manipulation errors. Therefore, the purpose of this study was to demonstrate the predictability of flapless surgery using navigation surgery through a series of case reports.

MATERIALS AND METHODS

Computer-generated preoperative implant planning was compared to actual placement by taking CT scans of patients before and after surgery.

Prior to considering implant therapy, patients received routine examination, prophylaxis, and initial disease-control treatments as needed. Once a need for CT scanning was determined, patients were informed about the new technology and agreed to undergo a pre- and postoperative CT scan. The criteria for flapless surgery were *(1)* adequate amount of bone for implant placement, ie, presence of 1 mm of bone buccolingual to the planned implant in a favorable prosthetic position as determined using the CT analysis, and *(2)* sufficient attached mucosa present at the surgical site such that at least 2 mm of attached gingiva would remain around the implant site circumferentially. Only patients qualifying for flapless surgery were entered in the study.

In preparation for CT examination, full-arch impressions were obtained using polyvinyl siloxane for fabrication of a scannographic template. This thermoformed acrylic occlusal splint extended to adjacent natural teeth for maximum stability and incorporated prefabricated barium-sulfate teeth (Ivoclar Vivadent, Amherst, NY, USA) in edentulous areas. A U-shaped prefabricated registration template was then attached to the splint. It contained embedded porcelain balls at precise locations: These fiducial landmarks were visible on the CT scan and later used to match the patient's position to the digital data.

Patients returned to the office for testing of the splint. In the event the splint was unstable, it was relined or modified until stability was obtained.

Patients then underwent CT scanning using a standard dental CT protocol while wearing the individualized occlusal splint intraorally. Scanning was performed on a GE LightSpeed scanner (GE Healthcare, GE, Fairfield, Connecticut, USA). After scanning, data files were exported and sent to the surgeon for analysis. Once imported into the software (DenX Advanced Dental Systems, Moshav Ora, Israel), a digital implant treatment plan was carried out using the specialized image-guided implantology (IGI) tools. The digital plan consisted of accurate graphics of virtual implants that were placed in 3D over the dental CT scan of the patient. Surgeries were initiated by repositioning the scannographic stents. Diode-equipped flags were attached to the stent and surgical handpiece. To register, or match, the stent position to the CT scan, steps were taken to identify the fiducial markers. The user made contact with the markers with the surgical handpiece and a specially designed bur. Consequently, the handpiece and stent were visible to high-definition cameras above the dental chair. Once identification was complete, software was able to overlay them on the CT data in real time. Osteotomies and implant placement were carried out while visualizing digital representations of burs and implants, overlaid onto the digital plan, on a monitor.

Following the implant surgery, patients were rescanned using the same occlusal splint mounted with the original registration mold. Using IGI software, the final position of the actual implants was identified on the postoperative CT scan and overlaid by the corresponding accurate graphics of the virtual implants by 1 examiner (Figs 1 and 2). This step was repeated. To compare implant planning to actual placement, coordinates (x,y,z) of centers of the platform and apices of the virtual implants on pre- and postsurgical CT data were exported. Coordinates were obtained in reference to fiducial markers to eliminate changes in patient positioning between CT scans.

Once pre- and postoperative coordinates of virtual implants were obtained, linear distances and angles were calculated. Coronal and apical errors consisted of the shortest distance from the preoperative planning to the postoperative overlay. This measurement was obtained by mathematically determining the coordinate of the projection of the initial virtual implant (center of the platform and

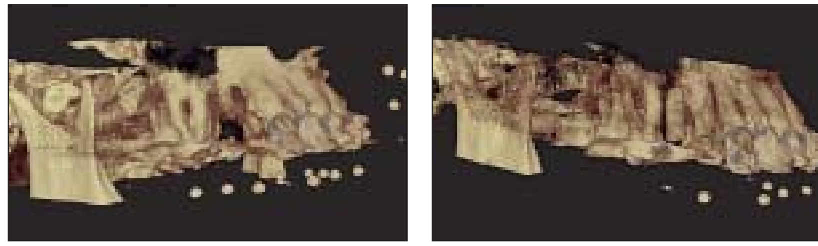

Fig 1 CT scans were performed before *(left)* and after *(right)* implant placement using the registration guide as reference.

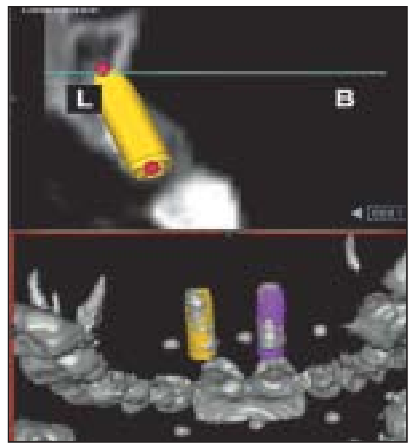

Fig 2 *(Left)* Overlay of virtual implants on scanned implants after placement. A computer delivered virtual implant coordinates.

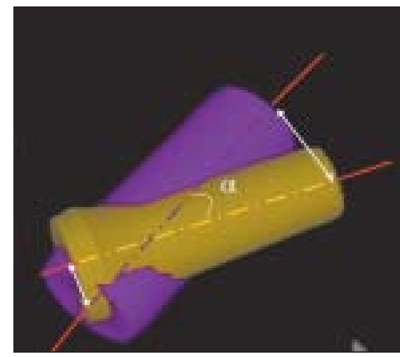

Fig 3 *(Right)* Angles between implants (α), as well as distances between platform and apex centers *(arrows)*, were calculated.

Table 1 Distribution of Implants

	No. of implants	Location by tooth no.	Manufacturer	Diameter (mm)	Length (mm)
Patient 1	2	8	Biolock*	3.45	10
		9		3.45	10
Patient 2	1	4	Ankylose†	3.5	11
Patient 3	1	19	Endopore Hybrid‡	4.75	9.5
Patient 4	3	28	Biolock*	3.45	11.5
		29		3.45	11.5
		30		4.0	11.5
Patient 5	6	19	Endopore Hybrid‡	4.75	9.5
		20		4.75	9.5
		21		4.0	9.5
		28		4.0	9.5
		29		4.0	9.5
		30		4.75	9.5
Patient 6	1	26	Endopore‡	3.5	9.0

*Biolock International, Deerfield Beach, Florida, USA; †Dentsply, Lakewood, Colorado, USA; ‡Innova, Toronto, Ontario, Canada.

center of the apex) onto the postoperative virtual implant and calculating the distance between these 2 points (Fig 3). Angles were calculated using the same 2 sets of coordinates.

RESULTS

Six patients were consecutively enrolled in a private-practice setting from April to June 2005. Two females and 4 males between the ages of 33 and 71 received 14 implants. The distribution of implants by patient is shown in Table 1. Each patient received between 1 and 6 implants for a total of 14 implants.

Table 2 Linear and Angular Deviations of Implants

Tooth	Head (mm)	Apex (mm)	Angle (degrees)
Patient 1			
Maxillary right central incisor	0.32	0.25	3.10
Maxillary left central incisor	0.39	0.36	0.60
Patient 2			
Maxillary right second premolar	1.15	1.17	6.08
Patient 3			
Mandibular left first molar	0.34	0.70	9.87
Patient 4			
Mandibular right first premolar	1.60	1.61	1.78
Mandibular right second premolar	1.28	1.33	2.92
Mandibular right first molar	1.96	1.99	2.87
Patient 5			
Mandibular right first premolar	1.13	1.09	1.93
Mandibular right second premolar	0.88	0.90	0.89
Mandibular right first molar	1.32	1.29	3.38
Mandibular left first premolar	0.32	0.34	0.76
Mandibular left second premolar	0.71	0.90	6.45
Mandibular left first molar	0.63	0.91	6.82
Patient 6			
Mandibular right lateral incisor	0.40	0.65	5.47
Mean/SD	0.89 ± 0.53	0.96 ± 0.50	3.78 ± 2.76

Average placement discrepancy at the implant platform was 0.89 mm ± 0.53 SD (range, 0.32 to 1.96 mm). At the apex, the average was 0.96 mm ± 0.50 SD (range, 0.25 to 1.99 mm). The average angle was 3.78 degrees ± 2.76 SD (range, 0.60 to 9.87 degrees) (Table 2).

DISCUSSION

The purpose of computer-assisted navigation surgery is the real-time monitoring of bone drilling and implant placement. This technology may be particularly useful in flapless surgery or osteotomy in proximity to critical anatomic landmarks.

The use of navigation relies on its accuracy. In vitro studies generally report high precision for optical navigation drilling, with averages within 1 mm or less.[11–14] Casap et al[6] found that the overall mean spatial navigation error was 0.35 mm ± 0.14 SD (range, 0.066 to 0.727 mm). This study was conducted on a jaw model in a laboratory environment. As discussed by the authors, this error was the result of multiple variables, including CT scan quality, precision of the tracking system, and degree of fit of the acrylic splint.

Computer-aided navigation, such as that utilized in the present research, differs from CAD/CAM fabrication of nonmodifiable guides. Preclinical research using these guides has yielded similar results. For example, in a laboratory evaluation of stereolithographic surgical guides, Sarment et al[9] demonstrated that CAD/CAM guides were more accurate than their conventional surgical counterparts. The average distance between the planned implant and the osteotomy was 1.5 mm at the entrance and 2.1 mm at the apex with conventional guides. These distances were significantly reduced to 0.9 mm and 1.0 mm, respectively, when stereolithographic guides were used.

However, these laboratory studies could not account for errors inherent to the clinical setting, such as patient movement during scanning, variations in bone densities, or operator manipulation.

Additional variables may be detrimental to accuracy when navigation is used: They include movement of the surgical splint during scanning and surgery or ease of access to the surgical site compared to bench drilling. In addition, errors can also result from divergence of the operator from the onscreen navigated path of drilling. In the present research, the additional postsurgical scan and 3D manual matching of a virtual implant over the implant in the postsurgical scan were also possible sources of error. Due to the multitude of potential sources for error and the small magnitude of the discrepancy, factors responsible for linear and angular deviations cannot be isolated in a clinical study. Despite these limitations, accuracy in the present report was similar to that achieved in laboratory settings—linear deviation was below 1 mm and angular deviation was about 4 degrees.

Other clinical reports have yielded similar results. In a clinical case series, Wagner et al[7] reported accuracy using an optical navigation system different from the one utilized in this research. Although they reported a mean linear deviation of 1.1 mm and a mean angular deviation of 6.41 degrees, ranges for linear deviation (0 to 3.5 mm) and angular deviation (0.41 to 17.41 degrees) were clinically significant. Using CAD/CAM guidance in a case series, Di Giacomo et al[10] reported a mean deviation of 1.45 mm (± 1.42 mm) at the implant shoulder and 2.99 mm (± 1.77 mm) at apices, resulting in average angulation deviation of 7.25 degrees (± 2.67 degrees). In a case series utilizing a neurosurgical navigation system adapted for dental implantation, Wittwer et al[8,9] reported deviations of less than 1 mm. These results are consistent with the present study despite the fact that linear measurements were taken from cortical surfaces to the implant apices, a method that has a potential for additional errors. Results of the current study compare favorably with these publications, but further investigation is necessary to identify causes. One possible explanation is that errors may have distinct origins, as illustrated by case 4 (Table 2): A high linear deviation but a low angular deviation suggests a translation, perhaps due to mispositioning of the splint.

Optical computerized navigation relies on a complex synchronization of imaging and reality, which is vulnerable to technological and technical errors. It is therefore vital that both the operator and assisting staff receive advanced training and that the equipment is properly calibrated. Nevertheless, the major advantage of computerized navigation is that even when deviating from the original plan, the new drilling path is monitored in real time to avoid complications. As a result, while linear or angular precision can diverge, the risk of cortical perforation in a flapless implant placement is reduced with potential to expand the use of this surgical approach.

Clinical studies on the accuracy of computer-generated guides and computer-aided navigation systems are hindered by the need for a postoperative CT scan causing unnecessary radiation exposure. With the advent of cone-beam CT, the ethical dilemma of radiographic exposure becomes less of an issue because the radiation dose is reduced by a factor of 10 or more as compared to traditional scanners. Furthermore, cone-beam CT yields greater image precision with potential to enhance clinical results. Further clinical trials are needed to evaluate specific factors, such as the operator and the location of the surgical site.

CONCLUSION

This preliminary study placing 14 implants in 6 patients highlights that surgical navigation for implant placement is technically sensitive but has potential to improve surgical accuracy. Despite the potential for errors, results showed less than 1 mm of mean linear deviation and less than 4 degrees of angular deviation.

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