Stereoscopic Technique for Conversion of Radiographic Guide into Implant Surgical Guide

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ABSTRACT

Purpose: The aim of this study was to develop and evaluate a new stereoscopic technique for conversion of radiographic guide into surgical guide for dental implant placement.

Materials and Methods: Ten partially dentate patients requiring 18 implants for tooth replacement were recruited. Radiographic guides were modified with the addition of index rods for double computed tomography scanning. Implant positions were planned with implant planning software, and the stereoscopic angulations were measured. The radiographic guides were converted into surgical guides using either a generic bench drill (Group A, $n = 9$) or a milling machine (Group B, $n = 9$). Stereolithographic surgical guides were also made for three patients (Group S, $n = 5$). Differences between the planned and actual angulations were tested by pair-sample t-test. Difference of mean angle deviation among groups was tested by Brown–Forsythe test. Differences were considered significant if $p < .05$.

Results: Eighteen implant sites were successfully treated with the converted surgical guides. The mean angle deviation of Group A ($1.3 \pm 0.6°$) was significantly greater than Group S ($0.4 \pm 0.6°$), while no differences were found between Group B ($0.9 \pm 0.3°$) and Group S. The linear error was greatest in Group A with 1.5 mm at the head and 1.8 mm at the apex of the implant.

Conclusions: The use of this new stereoscopic technique appears to be an acceptable alternative method for converting radiographic guide into surgical guide.

KEY WORDS: computer-aided design, dental implant, implant placement, radiographic guide, stereoscopic technique, surgical guide

INTRODUCTION

The success of dental implant treatment depends much on the three-dimensional position of implant in the jaw bone and its relation with adjacent teeth, vital structures, and the occlusion.[1] A malpositioned or misaligned implant often poses problems at the time of surgery or during fabrication of the prostheses. It may jeopardize the aesthetic outcome and may have more biological and technical complications in the long term.[2,3] Over the years, the precision of implant placement had relied solely on the skill and experience of the surgeons.[4] Today, with the advancement of digital technology and imaging techniques, clinicians can evaluate the bone anatomy in greater details and determine the best position for implant placement. Many commercial systems are now available for transferring the planned implant to the surgical site. They are either using stereolithographic technology like SimPlant/SurgiGuides (Materialise, Leuven, Belgium),[5–7] Procera/NobelGuide (Nobel Biocare AB, Goteborg, Sweden),[8–10] ImplantMaster (I-Dent, Ltd., Hod Hasharon, Israel),[11] or applying fiducial markers like EasyGuide (Keystone Dental, Burlington, MA, USA),[12] some manufacturers develop a combination of computer implant planning and real-time localization devices to guide drilling through the surgery like Image-Guided Implantology system

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(DenX Advanced Dental Systems, Moshav Ora, Israel),[13] VISIT navigation system (University of Vienna, General Hospital, Vienna, Austria), and Treon navigation system (Medtronic, Minneapolis, MN, USA).[14] However, the accuracies of these systems have been shown to be varied;[15–17] furthermore, these systems are usually costly and some of them are implant specific, precluding their use in other implant systems. To overcome these problems, this study was aimed (1) to develop a simple, accurate, and economic surgical guide for transferring the planned implant to the surgical site using stereoscopic technique and (2) to evaluate the accuracy of this method.

MATERIALS AND METHODS

Recruitment of Subjects

From August 2008 to December 2008, 10 consecutive partially dentate patients who required one to three dental implants were recruited. Patients who needed immediate implant placement, bone augmentation procedures, or who had extensive tooth loss where a stable tooth-supported surgical guide could not be fabricated were excluded. Orthopantomogram and periapical radiographs were taken for initial radiographic assessment. Each patient received a comprehensive preoperative evaluation followed by preventive and restorative treatments.

Preparation of Radiographic Guide

A diagnostic wax-up of the missing teeth was made on the study cast. The wax-up was then converted into a radiographic guide using clear acrylic resin (Vertex™ Self Curing, Vertex-Dental, Zeist, the Netherlands). Six to eight gutta percha markers were inserted into the guide following the NobelGuide™ Concept (NobelGuide Concept manual, Nobel Biocare). A total of 10 radiographic guides with 18 sites were prepared. The patient was asked to occlude on the radiographic guide together with a wax wafer while the cone-beam computerized tomography (CBCT) (EPX Impla, E-Woo, Korea) was being taken. The default scanning parameters were selected: 15 seconds scanning time, no metal suppression, 0.3 mm voxel size, and 12 × 7 cm field of view.

After CBCT scanning, three acrylic rods (Ø3 mm) were added onto the radiographic guide as indexes for stereoscopic graphical measurement. The three parallel acrylic index rods were placed perpendicular to the occlusal plane, and the top of the rods were marked with black ink for easy identification (Figure 1). The positions of the rods are at right angle to the others in the occlusal plane without interfering the trajectory of the planned implants (Figure 2). The modified radiographic guide was then mounted on the computed tomography (CT) machine for another CBCT scan. Both CT data of the patient and the radiographic guide were imported into the implant planning software – Procera® Clinical Design Premium (Nobel Biocare AB, Goteborg, Sweden).[18]

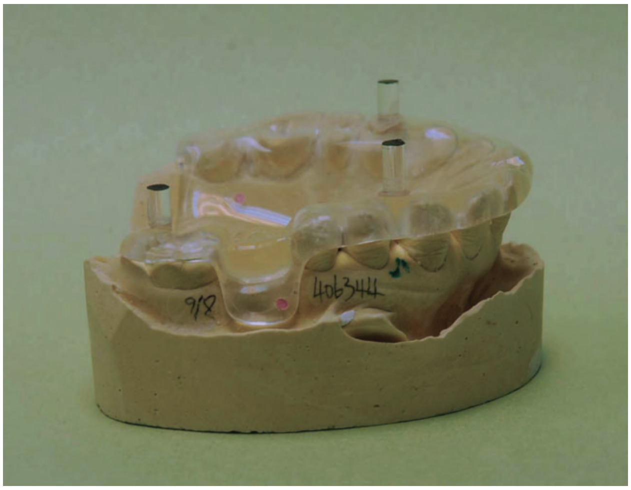
Figure 1 Acrylic rods widely distributed and their tops painted in black.

Implant Planning

Once the optimal implant position had been determined using the software (Figure 3), the image of the planned implant together with the guide was then

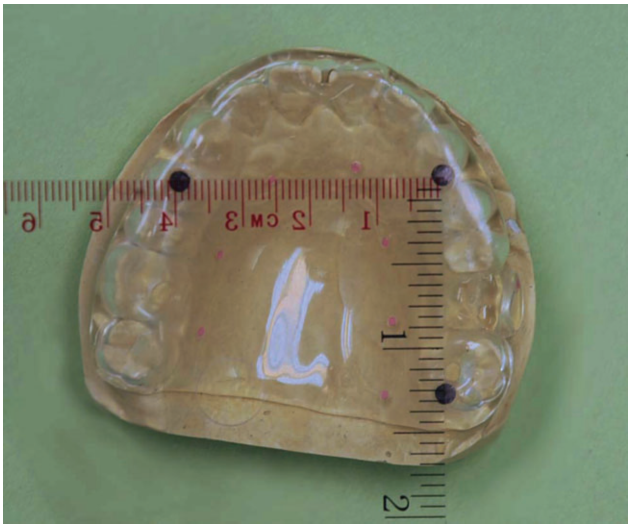
Figure 2 Acrylic resin rods formed a right angle.

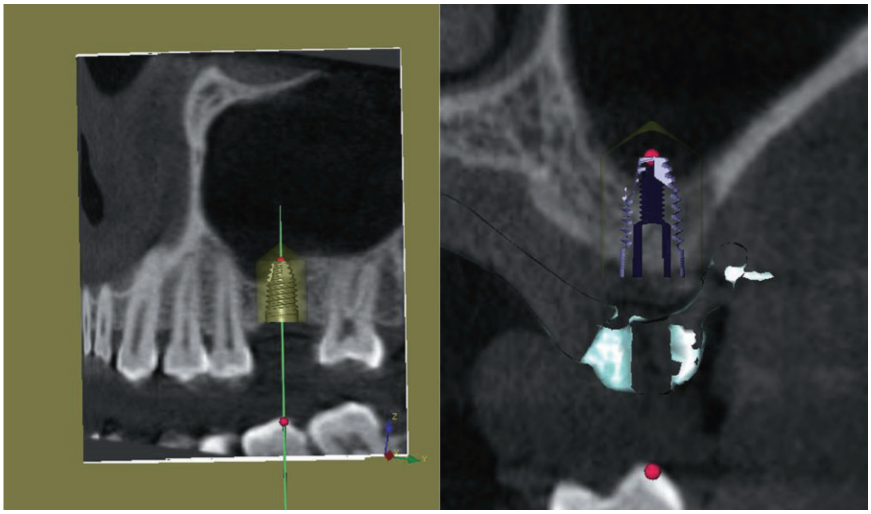

Figure 3 Implant planning using Procera® Clinical Design Premium software.

displayed in the three-dimensional scene window and oriented at the buccal view until one pair of the rods' tips were superimposed (Figure 4). The image was then captured. These steps were repeated for the frontal view where another pair of the rods' tips were superimposed (Figure 5). A computer screen measuring tool (e-Ruler, http://www.mycnknow.com/eruler.htm) was used to measure the angle between the implant's axis and the line joining the rod tips to the nearest 0.5 degree on the two captured images (Figures 4 and 5). The entry point for drilling was also marked by capturing the geometric distances from the rods' tip (Figure 6).

Preparation of Surgical Guide

Two machines were used in this study to prepare drill channels in the surgical guides. Machine A (ZB2506; Ningbo Dacheng Machinery & Electrical, Zhejiang, China) was a generic bench drill with a separated universal table, which could provide two planes of movement (Figure 7). Milling Machine B (Metaux Precieux; Neuchatel, Switzerland) was equipped with a fully adjustable ball-lock universal table specially designed for the dental laboratory (Figure 8). For the bench drill, the model with the radiographic guide was mounted with the index rods in line with the two axes of the universal

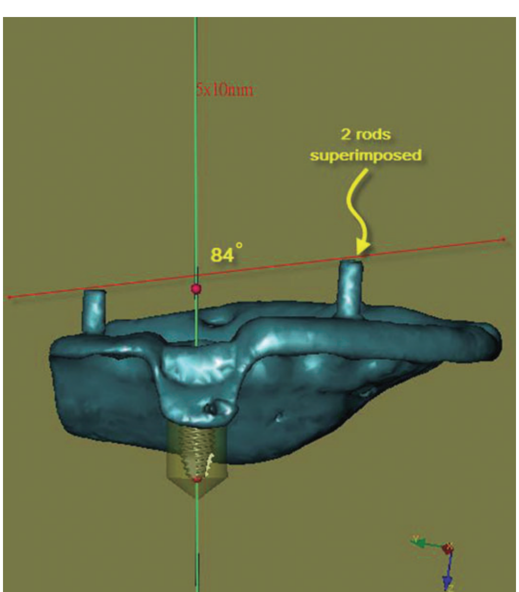

Figure 4 Buccal view measurement.

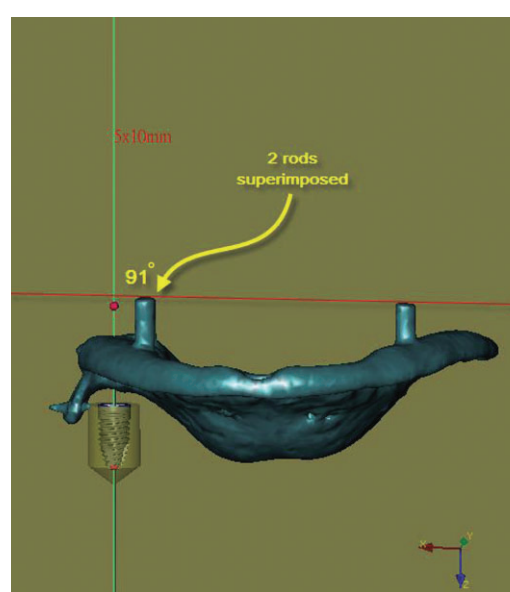

Figure 5 Frontal view measurement.

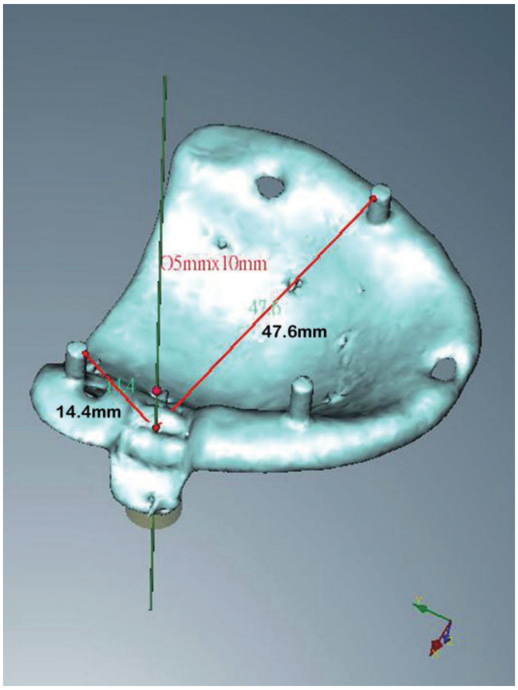

Figure 6 Drill entry point.

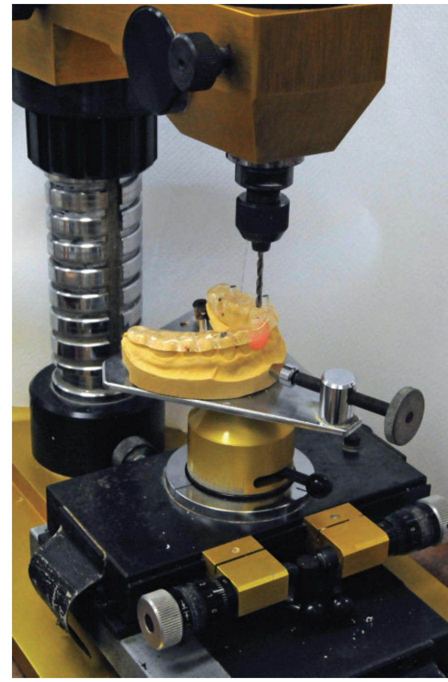

Figure 8 Milling machine with fully adjustable universal table.

table (Figure 9). For the milling machine, this step was not needed.

The universal table was set according to the angular measurements with a clinometer (Niigata Seiki, Niigata, Japan) (Figures 10 and 11). The drill entry point was marked on the guide according to the geometric measurements of the Procera software (Figure 12) and a Ø2.8 mm channel was prepared with cylindrical drills (Figure 13). A 5 mm long stainless steel tubing, with an external diameter of Ø2.8 mm and an internal diameter of Ø2 mm (K.C. Smith Ltd, Potter Bar, England) was fitted into the bottom of the channel and secured with Loctite® Medical Device Adhesive (Henkel Corporation, Rocky Hill, CT, USA) (Figure 14). The radiographic

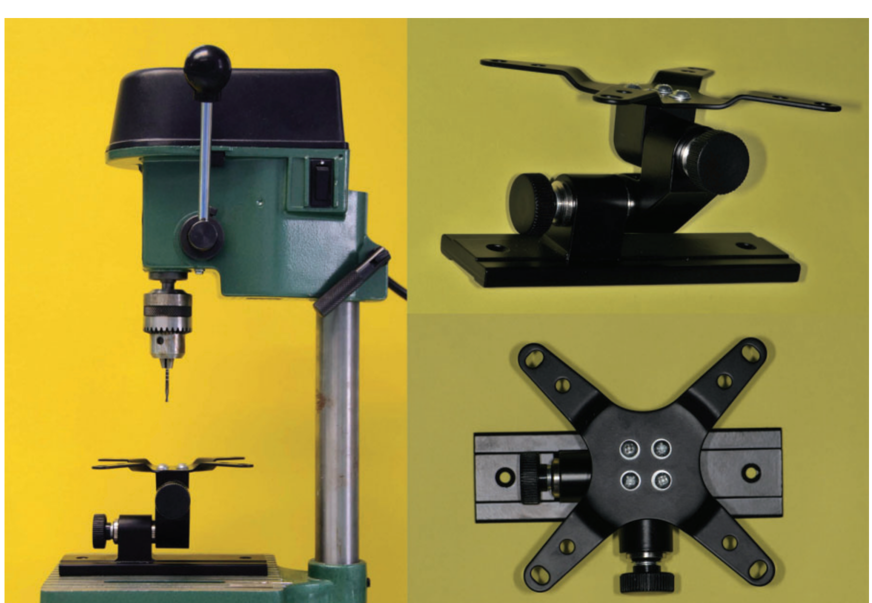

Figure 7 Bench drill with detachable universal table.

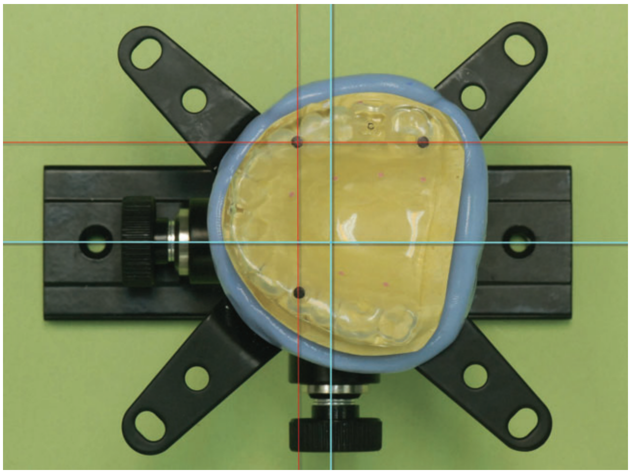

Figure 9 Rods in line (red) with axes (blue) of the universal table.

guide was thus converted to a surgical guide with Ø2 mm drill sleeve.

Accuracy Verification

In order to verify the precision of the converted surgical guide, a Ø2 mm wooden rod was placed into the drill sleeve for the third CBCT scan (Figure 15). The data were transferred into the Procera software again and by superimposing the acrylic rods' tips of the guide as

Figure 10 Universal table orientation with clinometer (buccal view).

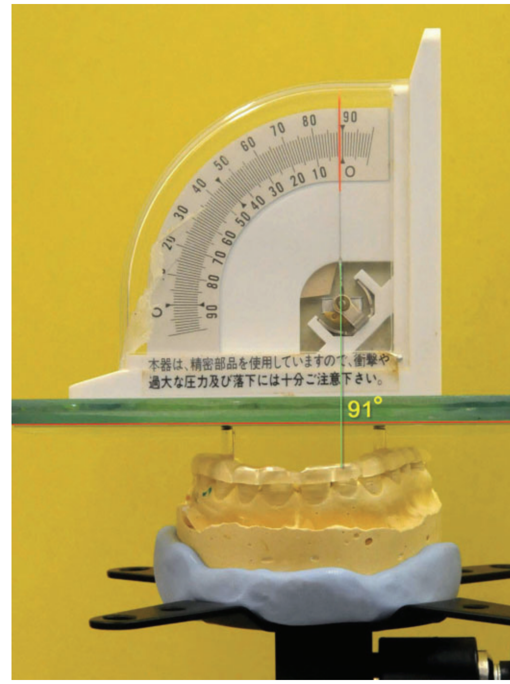

Figure 11 Universal table orientation (frontal view).

mentioned before, buccal and frontal view images were captured for angular verification (Figure 16). The isovalue of the radiographic guide was set to −1000 in order to show the wooden rod. For linear verification, the same treatment planning was reloaded into the planning software. A superimposition image was obtained (Figure 17). The reslice plane was attached to the planned implant, and the plane was rotated to view the maximum linear deviations at the implant head (Figure 18) and apex (Figure 19). Since Procera software can only measure distance greater than 0.5 mm, the computer screen distance was measured by screen

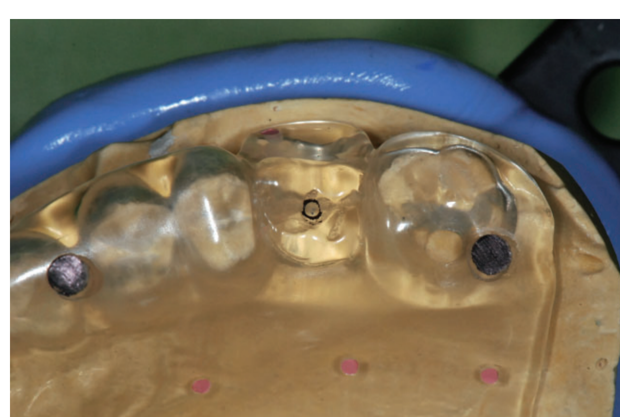

Figure 12 Drill entry point.

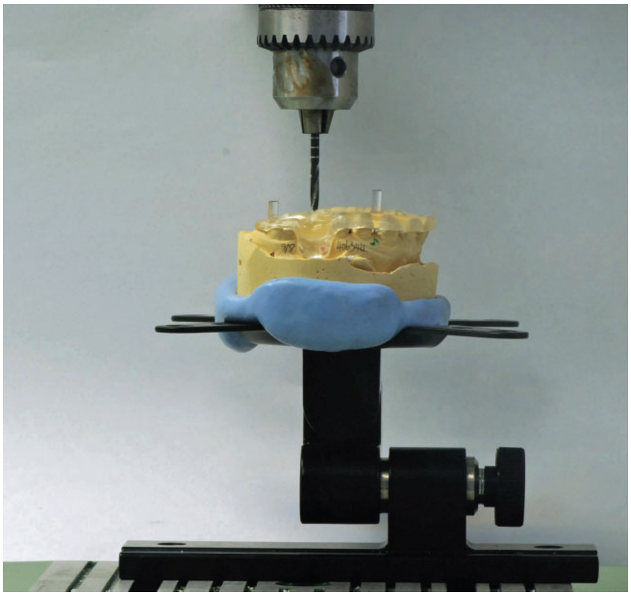

Figure 13 Channel drilling.

measuring tool (e-Ruler), and the actual linear deviation was calculated using scale and ratio formula.

The angle deviation of the stereolithographic surgical guides fabricated by the Procera production facility using the same implant planning was verified using digital photography. By superimposing the rods' tips of the guide as mentioned before, buccal and frontal view photograph were taken from the same viewing angles as the computer generated images (Figure 20). In order to minimize any potential distortions, a digital camera (Nikon Imaging Japan Inc., Minato-ku, Tokyo, Japan) with a lens of long focal length (200 mm) was mounted on a stable tripod 1.5 m away the cast. The images were then measured using the same computer screen

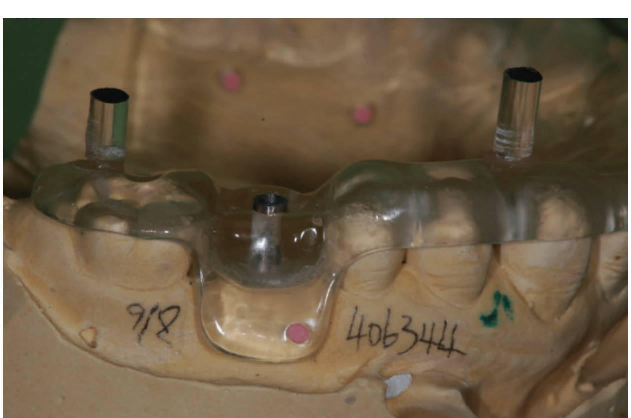

Figure 14 Surgical guide with 2 mm internal diameter drill sleeve.

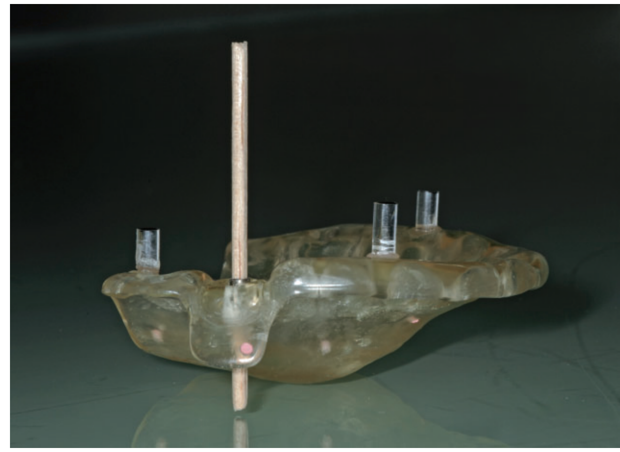

Figure 15 Converted surgical guide with a wooden rod.

measuring tool (e-Ruler) for angle verification. A geometry formula, $\tan^{-1}(\sqrt{(\tan(\text{buccal angle})^2 + \tan(\text{frontal angle})^2)})$, was used to calculate the angle deviation of the converted guides and the stereolithographic surgical guides. The linear deviation of the stereolithographic guide at the apex was calculated mathematically by another formula, $2 \times (\text{drill elongation length} + \text{implant length}) \times \sin(\text{angle of deviation}/2)$. These calculated results were true under the assumption: the entry point of the drilling was transferred correctly from computer planning to the stereolithographic guide.

Data Analysis

All data were analyzed using SPSS (version 17.0) software (IBM® Corporation, NY, USA). Considering 1.0 mm linear deviation to be clinically significant for a 15 mm implant, detection threshold of angular deviation 3.8° is needed. The sample size was estimated to be five with 90% statistical power. Normality of the data was checked by the Shapiro–Wilk test. Differences between the planned and final angulations for guides made by machine A (Group A), machine B (Group B), and stereolithographic technique (Group S) were tested by pair-sample *t*-test. Differences of mean angle deviation between the groups were tested by the Brown–Forsythe test. Bonferroni multiple comparisons were performed for post hoc analysis. Differences were considered significant if $p < .05$.

RESULTS

Ten subjects were recruited, and a total of 18 implant sites were evaluated. The subject particulars and implant characteristics are shown in Table 1. The mean age of the

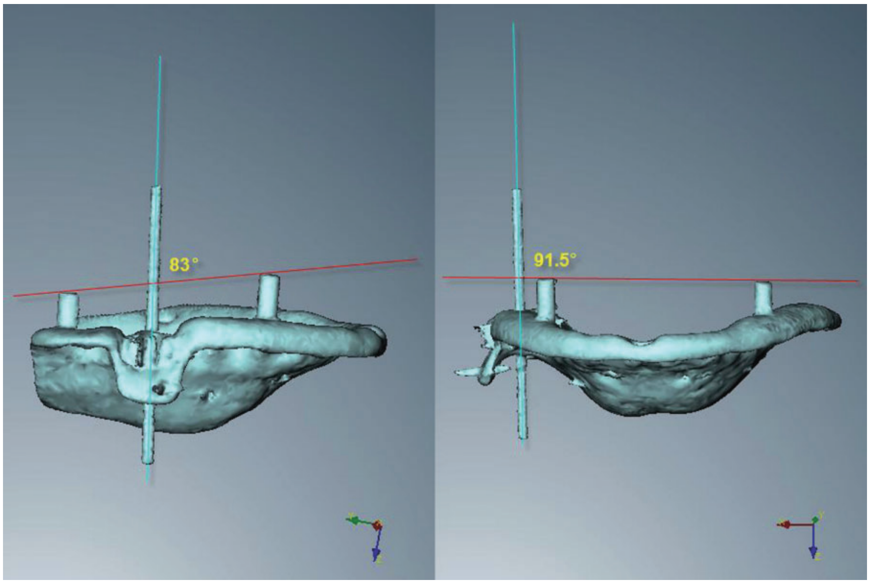

Figure 16 Images for angular verification.

subjects was 52.9, and seven of them were males. All converted surgical guides were verified with the digital photographic images before surgery. All patients were successfully treated using the converted surgical guides (Figure 21). Three patients have both a converted surgical guide and a stereolithographic surgical guide (Table 1). Figure 22 compared the clinical results with the planned position using a postoperative radiograph.

The mean angle deviations of different groups are shown in Table 2. With the exception of frontal angulation of Group A ($p < .001$), no significant differences were found between the planned and final angulations in all groups ($p > .05$). There was a significant difference of the mean overall angle deviation among groups ($p = .04$). Post hoc tests showed the mean overall angle deviation of Group A was significantly greater than Group S.

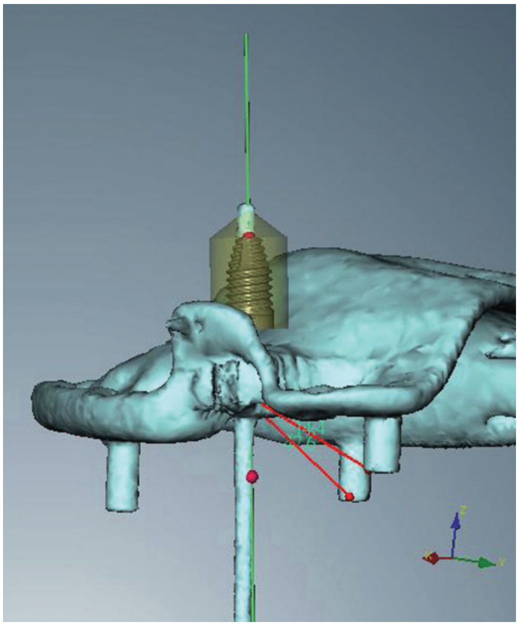

Figure 17 Converted guide superimposed with the computer planning.

TABLE 1 Subject Particulars and Implant Characteristics

Case Number	Gender	Age	Implant Sites	Implant Length (mm)	Group
1	F	48	26	10	A, S
2	F	64	37	7	A, S
			46	7	A, S
3	M	77	33	13	A, S
			36	10	A, S
4	M	45	36	13	A
			46	10	A
5	M	67	36	10	A
			37	10	A
6	M	48	24	13	B
			25	13	B
			26	11.5	B
7	F	39	36	10	B
8	M	68	24	13	B
			25	13	B
			26	11.5	B
9	M	41	36	13	B
10	M	32	31	13	B

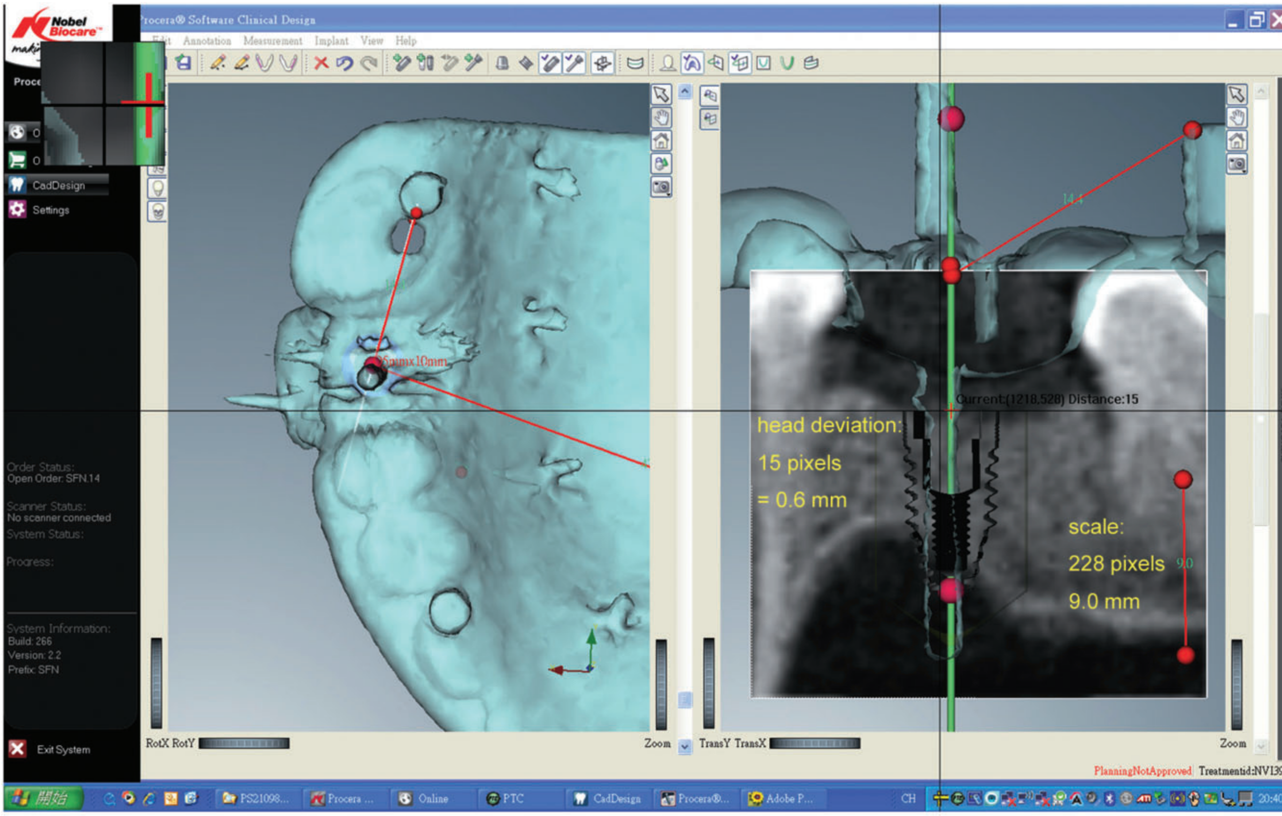

Figure 18 Head deviation.

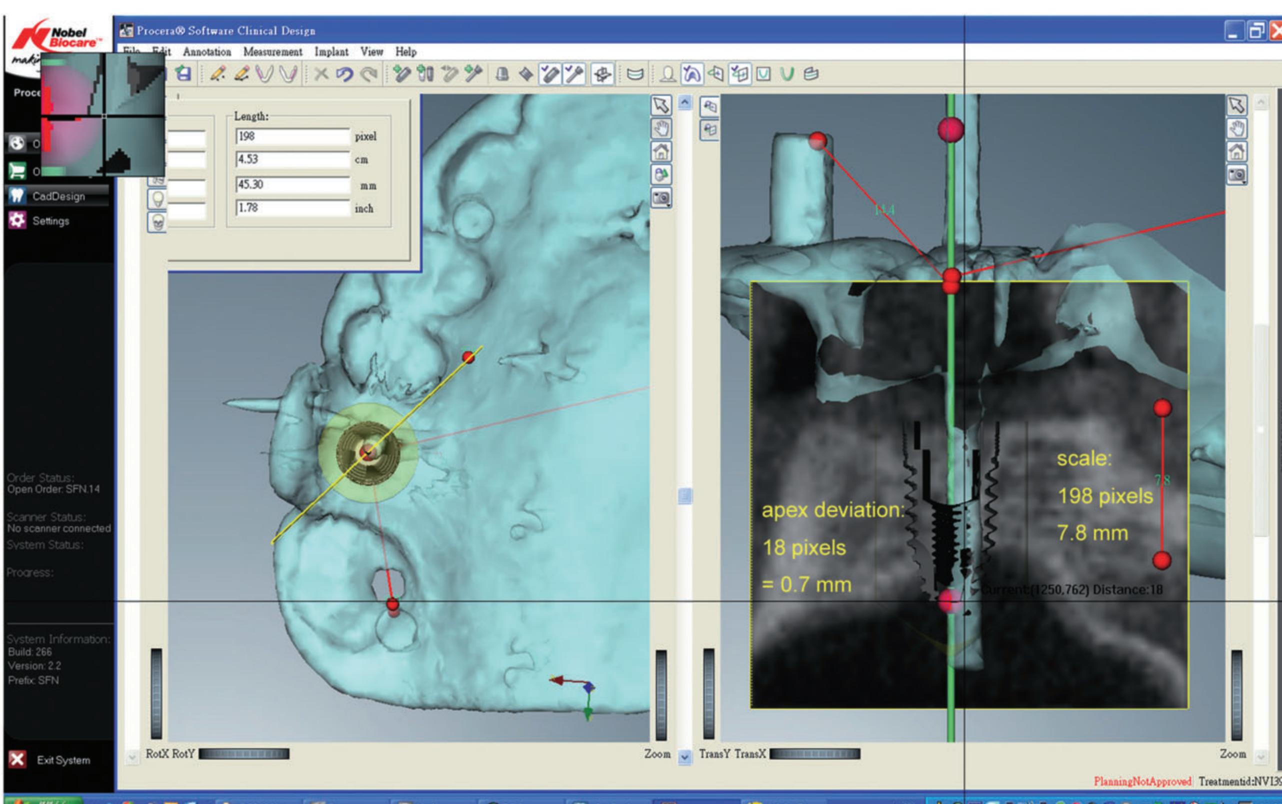

Figure 19 Apex deviation.

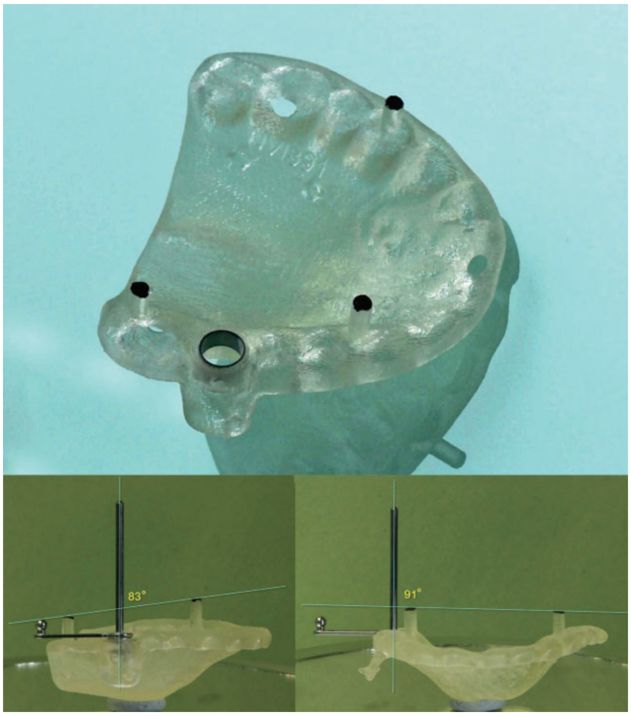

Figure 20 Stereolithographic surgical guide verification.

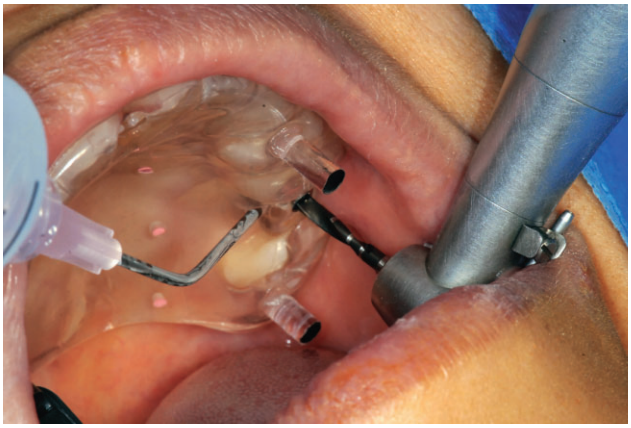

Figure 21 Initial drill guided during implant surgery.

TABLE 2 Mean Angle Deviation among Groups

Group	Buccal	Frontal	Overall*
A ($n = 9$)	0.6° ± 0.6	0.9° ± 0.6†	1.3° ± 0.6
B ($n = 9$)	0.7° ± 0.4	0.4° ± 0.3	0.9° ± 0.3
S ($n = 5$)	0.4° ± 0.5	0.1° ± 0.2	0.4° ± 0.6

*Significant difference among three groups ($p = .04$; Brown–Forsythe test), significant difference between two groups (A > S, $p = .022$; post hoc Bonferroni test).
†Significant difference between planned and final angulations ($p < .001$; pair-sample T).

The mean linear deviations of different groups are shown in Table 3. The maximum linear error at the head and apex of the implant in Group A was 1.5 and 1.8 mm, respectively. The maximum linear error at the head and apex of the implant in Group B was 0.5 and 1.3 mm, respectively. The maximum linear error at the head and apex of the implant in Group S was 0.2 and 0.4 mm, respectively.

DISCUSSION

The success of computer-guided implant therapy depends heavily on the accurate transfer of the planning to the surgical site.[19] Computer-aided design/computer-aided manufacturing (CAD/CAM) guided implant procedures have been shown to be accurate and predictable in implant treatment from surgery planning to prosthesis fabrication.[20] Many different methods have been advocated for this purpose.[15] Most of the CAD/CAM systems allow implants to be placed virtually in a stereoscopic dimension, using data from a CT scan. The resulting planned implant can be transferred to the surgical

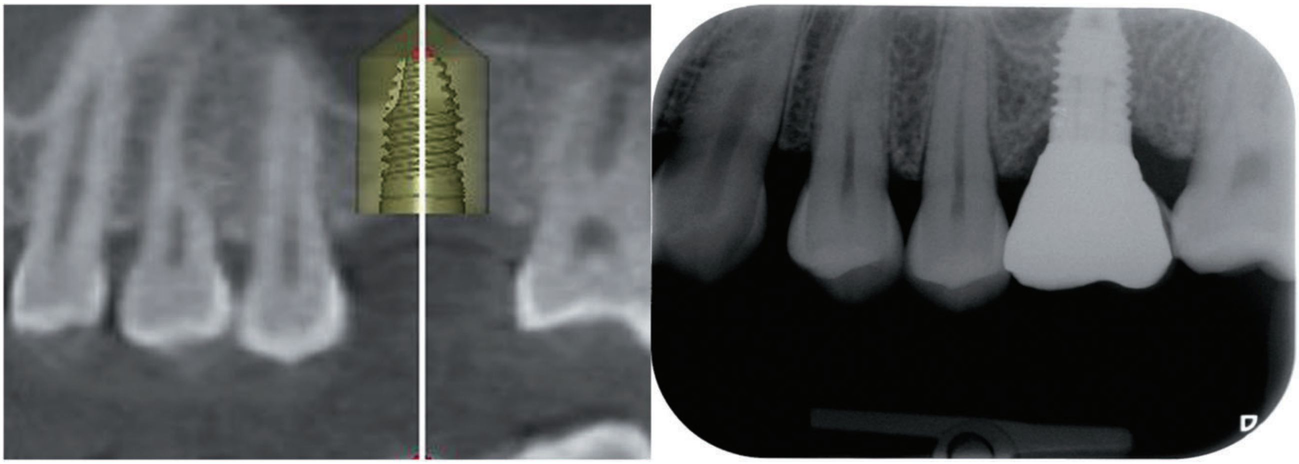

Figure 22 Compare planning with the final outcome.

TABLE 3 Mean Linear Deviation of the Converted Guides

Group	Implant Length	Head	Range	Apex	Range
A ($n = 9$)	10 ± 2.1 mm	0.6 ± 0.4 mm	0.2–1.5 mm	0.9 ± 0.4 mm	0.4–1.8 mm
B ($n = 9$)	12.3 ± 1.1 mm	0.3 ± 0.1 mm	0.1–0.5 mm	0.7 ± 0.4 mm	0.1–1.3 mm
*S ($n = 5$)	9.4 ± 2.5 mm	0.1 ± 0.1 mm	0.0–0.2 mm	0.1 ± 0.2 mm	0.0–0.4 mm

*Estimated values based on the total height from drill entry and angular deviation.

field and installed by means of a stereolithographic surgical guide[8] or a numerically drilled template. The main disadvantages of this rapid prototyping technology are the occasional misfit of the guide in dentate arches and the high cost. On the other hand, fiducial markers solve these problems by converting the radiographic guide directly into a surgical guide. One of the example published by Holst and colleagues[21] attached a Lego block as a fiducial marker on the barium sulfate-coated radiographic guide. After CT scan and computer implant planning (implant3D; med3D, GmbH, Heidelberg, Germany), the radiographic guide was converted into a surgical guide with a special transfer drill stand (Positionierer X1, med3D). Fortin[22,23] fixed a cube in front of the radiographic guide with radiopaque teeth for the scanning procedure. The cube is the fiducial marker (X Marker), which contains two titanium tubes to coordinate the EasyGuide planning software (Keystone-Dental, Burlington, MA, USA) and the numerically controlled drilling machine. Thus, the radiographic guide can be precisely converted into a surgical guide. However, these two methods require special mechanical tools exclusively designed for the virtual planning software, while the conversion method described in this article is not system specific, and the conversion process can be carried out in a dental clinic with a generic bench drill. Another advantage is that the converted guides are the same guides used for CBCT scan; this eliminates the common fitting problems[24] of stereolithographic surgical guides. In addition, this surgical guide controls the first drilling precisely while allowing flexibility for latter drillings. The surgeon could modify the surgical plan during the surgery.

The use of e-Ruler to measure angle or linear deviations on the screen was to compensate the shortfalls of Procera software. For surgeons using the most updated Procera software (NobelClinician), an enhanced measuring tool is a built-in feature; accurate measurements can be obtained without using third-party utilities. Two methods were employed to verify the angular accuracy of the conversion process. In groups A and B, the converted guides were scanned again, and the data were re-loaded into the Procera software for comparison, while for Group S, as there were no gutta percha markers in the stereolithographic surgical guides, the photographic technique was used to compare the guides with the original plannings. Both techniques were tested in Groups A and B, and no significant differences were found. For linear calculation, unlike Groups A and B, direct linear deviation measurements could not be measured in Group S, so the deviations were calculated mathematically based on their angular deviations.

The main concern of computer planning is the degree of accuracy between the planned position of the implants and the surgical outcomes. Besimo and colleagues[25] evaluated the magnitude of errors in transferring the Simplant® (Materials Inc., Leuven, Belgium) planning of implants from CT scans to a manual fabricated surgical guide; the transfer error was 0.6 mm (SD 0.4) in the maxilla and 0.3 mm (SD 0.4) in the mandible with a maximum deviation of 1.5 mm at the apex. Other studies[9,10,26,27] measured the accuracies of stereolithographic surgical guides are shown in Table 4. A wide range of differences between the planned and the actual implant positions have been reported, and the errors might be due to the misfit of the stereolithographic guides on teeth or to the instability of the guides on bone.[24]

From the results (Table 2), the stereolithographic surgical guide fabricated by the manufacturer matched accurately with the computer-generated images. The mean angular error of Group S was small of 0.4°with a maximum 1.1° deviation. Group B gave similar results, while Group A produced a larger mean angular error of 1.3° and that was probably due to the less stable universal table of Group A than the one used in Group B.

Regarding the linear measurements, although the results of Group S seem to be more accurate than those

TABLE 4 Accuracy of Stereolithographic Surgical Guides

	Accuracy at Head	Accuracy at Apex	Accuracy of Angulation	Program
van Steenberghe et al. 2002[9]	0.8 ± 0.3 mm	1.0 ± 0.6 mm	1.8 ± 1.0°	Litorim
Sarment et al. 2003[26]	0.9 ± 0.5 mm (Max 1.20 mm)	1.0 + −0.6 mm (Max 1.60 mm)	4.5 ± 2.0° (Max 5.40°)	Simplant
Di Giacomo et al. 2005[24]	1.45 ± 1.42 mm (Max 4.50 mm)	2.99 ± 1.77 mm (Max 7.10 mm)	7.25 ± 2.67° (Max 12.20°)	Simplant
Van Assche et al. 2007[10]	1.10 ± 0.70 mm (Max 2.30 mm)	1.20 ± 0.70 mm (Max 2.40 mm)	1.80 ± 0.80° (Max 4.00°)	Procera
Ozan et al. 2009[27] (teeth support)	0.87 ± 0.40 mm (Max 1.80 mm)	0.95 ± 0.60 mm (Max 2.20 mm)	2.91 ± 1.30° (Max 5.60°)	Stent CAD
Schneider et al. 2009[17] (Systematic review)	1.11 mm (95%CI: 0.94–1.28 mm)	1.53 mm (95%CI: 1.19–1.87 mm)	4.87° (95%CI: 3.62–6.12°)	

CI = confidence interval; CAD = computer-aided design.

of the other two methods, it should be noted that the data of Group S were not absolute values but rather were estimated mathematically based on implant length and angular deviation instead of image superimposition. In addition, the mean implant lengths of groups A and B were longer than those of Group S; therefore, any analyses performed will be biased in favor of Group S. On the other hand, the mean and maximum linear errors of Groups A and B seem comparable with the data of the systematic review by Schneider and colleagues.[17]

It should be pointed out that the protocol suggested in this study has some limitations. First, it can apply only to a dentate arch, as there is no anchor mechanism other than the existing teeth. Second, implant planning software and CT scan are required. Third, the accuracy of this technique relies on the three-dimensional geometric output of the implant planning software. Other drawbacks of this method include the extra task of adding the acrylic rods before the second CBCT scan, the time needed for preparation of the channel, and the possible operator's error in locating the entry point during drilling.

The present study included only 10 patients, and the final postoperative implant positions were not measured; further exploration in matching the final clinical outcome with the planning is needed.

CONCLUSION

This article described an alternative method of converting a radiographic guide into a surgical guide, and the accuracy is comparable with other advocated techniques.

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