Accuracy of implant placement using precision surgical guides with varying occlusogingival heights: An in vitro study

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Statement of problem. Surgical guides may interfere with effective use of surgical instrumentation during implant placement in the posterior segments where interocclusal distance may be limited.

Purpose. The purpose of this study was to measure and compare the accuracy of posterior implant placement using 3 precision surgical guides with varying occlusogingival heights, and to evaluate the difference in accuracy of implant placement through precision guides as compared to freehand placement.

Material and methods. Three groups of surgical guides were fabricated with occlusogingival heights of 4, 6, and 8 mm, respectively. A jig was fabricated to allow for accurate positioning in bone substitute blocks. Ninety implants were placed in the mandibular first molar site on a manikin. Thirty implants (Astra Tech AB) were placed for each group, with 15 through the guide and 15 freehand. Distances between a reference implant and each placed implant were measured at both implant and abutment levels using a coordinate measuring machine. Apex position and angular discrepancy were calculated using the coordinates of the centers of the implant platform and of the occlusal aspect of the abutment. Data was assessed using 2-way ANOVA (α=.05).

Results. Two-way ANOVA demonstrated that guide height did not significantly affect the accuracy of the implant position. The distance from the reference point to the point of measurement was significantly smaller for placement through the guide compared to freehand placement at both implant (P<.001) and abutment levels (P<.001). The angular discrepancy was also significantly smaller for placement through the guide (P<.001).

Conclusions. Precision surgical guides with 4-mm occlusogingival height allow placement as accurate as precision guides with 8-mm height. Placement through the guide reproduced the target position more accurately than freehand insertion. (J Prosthet Dent 2009;101:372-381)

Clinical Implications

Precision surgical guides with 4-mm occlusogingival height may provide adequate accuracy for implant placement. Reducing the occlusogingival height of the guide may ease the use of precision-guided surgery without compromising the accuracy of implant placement.

The success of implant-supported restorations is not only related to the level of implant integration in the bone but also to the position of the implant. Implant position may affect the esthetics and function of the restoration. Restoratively driven treatment planning and implant placement require precise assessment of

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the surgical site. It must relate the desired type and 3-dimensional location of the prospective restoration to the necessary implant location. That position must be communicated from the restorative dentist to the surgeon.[1] A surgical guide is an effective method to accomplish communication of the goal.

Surgical guides for implant placement have been used to enhance accurate positioning of implants. Many types of surgical guides have been developed and used in dentistry. Generally, the surgical guide fabrication process begins with a diagnostic tooth positioning, either through a diagnostic waxing, denture teeth arrangement, or via the duplication of the preexisting dentition/restoration.[2] Fabrication techniques may vary in the manner of transferring such diagnostic information to a surgical guide and the guide's application during surgery. Surgical guides may be categorized based on the material used and amount of surgical restriction. Clear vacuum-formed matrices,[3] with or without the use of autopolymerized acrylic resin,[4] and gutta-percha[5] or metal rods[6-8] for contrast and radiographic assessment, have been used in the past. Autopolymerized acrylic resin has also been widely used for the fabrication of surgical guides. Parel and Funk[9] made acrylic resin guides with facial contours, only. Akca et al[10] used a channel guide placed into an autopolymerized acrylic resin guide. Sicilia et al[11] placed 2 wires occlusally and gingivally, which were bent following the facial contour of the proposed restoration in the edentulous area. The authors used autopolymerized acrylic resin to secure these wires in the dentate area. These wires were used to maximize the visibility of the surgical site instead of acrylic resin. Other materials, such as light-polymerizing composite resin tray material[12] or a combination of acrylic resin and composite resin, have been used as alternatives, as well.[13] More restricted types of guides were also introduced to guide drills with sleeves or channels. Burns et al[14] set metal tubes in the guide using a surveyor at the proposed center of restoration with the desired angulation and used acrylic resin to fix the tubes in place. Disks and incremental tubes or channels were also used to guide drills sequentially.[15-19] Cehreli[19] used 2-, 3-, and 3.8-mm incremental tubes in acrylic resin surgical guides along with computerized tomography (CT)-derived data.

Recently, new surgical guides have been developed for precise implant placement, so that a definitive or an interim prosthesis may be fabricated prior to surgery. Precision surgical guides may be defined as metallic guides closely matched to the diameter of the drills and/or implants. These guides are fabricated with the aid of computer-assisted design/computer-assisted manufacturing (CAD/CAM) technology and rapid prototyping.[20,21] CAD/CAM-generated surgical guides in conjunction with cone-beam computerized tomography (CBCT) have expanded the possibilities in terms of presurgical treatment planning and accurate implant placement. Several articles were recently published on the accuracy of computer-aided implant surgery.[22-30] Two different techniques have been developed for computer-aided implant surgery: stereolithographic surgical guide techniques and navigation using optical tracking techniques. Ruppin et al[22] evaluated the accuracy of 2 optical tracking systems and 1 stereolithographic guide in vitro using human mandibles. They found no significant difference in the accuracy of implant placement using the 3 systems. All 3 groups showed mean deviation of no more than 1.5 mm buccolingually and 0.8 mm in vertical depth. Wanschitz et al[24] showed a mean of 0.96 mm lateral deviation using the optical tracking technique. Sarment et al[31] compared a conventional guide, which was modified from a radiographic guide, to a stereolithographic surgical guide using CBCT in vitro. Results showed that the mean distance between the planned implant placement and the actual osteotomy was significantly smaller for the stereolithographic guide as compared to the conventional one. van Steenberghe et al[32] examined the accuracy of a CAD/CAM surgical guide in cadavers, and Vrielinck et al[33] performed a similar study in human subjects. In a review article, Vercruyssen et al[30] discussed possible errors of CAD/CAM surgical guides, which may occur at any of the following stages: CT-scan data collection, positioning of the radiographic guide, segmentation of bone, teeth, and/or tissue from the complete image, stereolithographic or CAD/CAM modeling, fixation of the surgical guide to the jaw bone, and use of precision sleeves. This type of precise surgical guide has also presented some challenges to clinicians. Yong and Moy[34] studied early complications using CAD/CAM-guided implant placement with the NobelGuide system (Nobel Biocare AB, Göteborg, Sweden). The authors found that the most common early surgical complication was incomplete seating of the prosthesis due to bony interferences.

Limited surgical access with surgical guides intraorally may be one of the most common challenges of using surgical guides. Surgical guides may interfere with effective use of surgical instruments in the posterior segments where interocclusal distance may be limited, especially for the partially edentulous patient. It is not uncommon that the surgical guide may be used only for the initial marking of the center, or for a portion of the osteotomy. Thus, surgical guides for implant placement should be designed not only as a precise and effective communication tool, but also to occupy minimum space so as not to interfere with the surgery. Choi et al[35] evaluated the effects of varied dimensions of surgical guides on implant angulations. The authors evaluated 3 variables, including the diameter of the surgical channels, the length, and the distance from the recipient site to the guide. The length of the channel seemed to be the primary controlling factor in

minimizing angular deviation. Choi et al[35] recommended the use of the longest channel possible. The study, however, was not conducted with an incremental drill guide system that corresponds to the sequential drill diameters.

The purpose of this in vitro study was to measure and compare the accuracy of implant placement in the mandibular molar region using 3 precision surgical guides with varying occlusogingival heights, and to evaluate the difference in accuracy of implant placement through the guides as compared to freehand placement. The research hypotheses were: (1) the occlusogingival height of the guide does not affect the accuracy of implant placement, and (2) guided implant placement is as accurate as freehand implant placement.

MATERIAL AND METHODS

Three groups of metal guides (35 mm (L) x 10 mm (W)) with varying occlusogingival heights (4, 6, and 8 mm) were fabricated. Three holes were precisely drilled into metal blocks with differing heights to fabricate the surgical guides. Two holes, 1 on each end, were used as positioning references for the guides. The diameter of these holes was 5.5 mm. The hole at the center, 5.7 mm in diameter, corresponding to the implant carrier (Facilitate; Astra Tech AB, Mölndal, Sweden), was used for aligning each drill sleeve and for implant placement (Fig. 1). Three guides were precisely machined to have identical dimensions except their heights, with 0.0002-inch machining tolerance (Bridgeport V2XT CNC Milling Machine; Hardinge, Inc, Elmira, NY). The guides were designed to slide over a metal jig that had 2 vertical beams with a diameter of 5.5 mm on a rectangular metal base. On each beam, a setting pin hole was drilled so that the setting pins could be positioned to stop the guides at the same vertical position. The setting pins were designed to be located 3 mm above a polyurethane bone substitute block (Pacific Research Laboratories, Inc, Vashon Island, Wash). A 3-mm-diameter V-shaped crater was machined on top of each beam to be used as a measurement reference (Fig. 2).

Bone substitute blocks were made of rigid polyurethane foam with a density of 0.48 g/cc. The dimensions of the blocks were 37 mm (L) x 14 mm (W) x 16 mm (H). Each block had 2 holes to fit the metal jig (Fig. 3). The blocks were designed to fit the metal jig with friction to minimize positioning errors. A drill guide was machined out of stainless steel and used to make positioning holes on the bone substitute block.

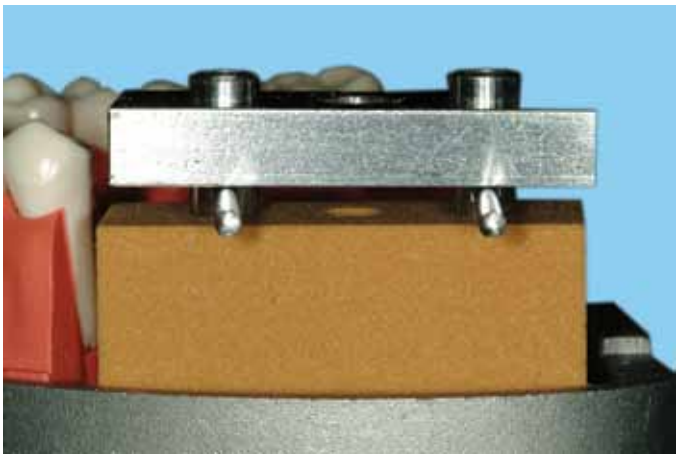
A typodont (ModuPRO Pros; Acadental, Inc, Woodson, Kan) was mounted in a manikin, and the metal jig was placed on the base of the typodont. The bone substitute block was placed onto the metal jig. Subsequently, the setting pins, made of 1-mm-diameter stainless steel rods, 10 mm in length, were placed onto the metal jig. One of 3 guides was positioned on top of the setting pins, leaving 3 mm of space between the bone substitute block and the guide. Plastic teeth in the mandible and the maxilla enhanced the simulation of actual surgery (Fig. 3).

Each guide group (4-mm, 6-mm, and 8-mm groups) was divided into 2 subgroups: the guided placement group and the freehand placement group. In this study, guided placement was defined as implant placement using the Facilitate (Astra Tech AB) implant carrier which fit the internal diameter of the surgical guide channel. Freehand placement was defined as implant placement using a regular implant carrier without a surgical guide after the osteotomy was prepared. Both groups used identical procedures for the drilling stages. For each of the subgroups, 15 implants were placed, for a total of 90 implants (OsseoSpeed demonstration implants, 4.0 x 11 mm; Astra Tech AB) (Table I).

A reference implant (OsseoSpeed demonstration implant, 4.0 x 11 mm; Astra Tech AB) was connected to the Facilitate implant carrier (Astra Tech AB). This assembly was placed at the center hole of the metal guide. The diameter of the center hole in the metal

1 Surgical guides with varying occlusogingival heights (8 mm, 6 mm, and 4 mm).

2 Metal jig (37 mm (L) x 14 mm (W) x 3 mm (H)) with V-shaped crater on top of vertical beams for measuring references and with setting pin holes to stop guides at same vertical position.



3 Assembly of metal jig, bone substitute block, setting pins, and surgical guide.

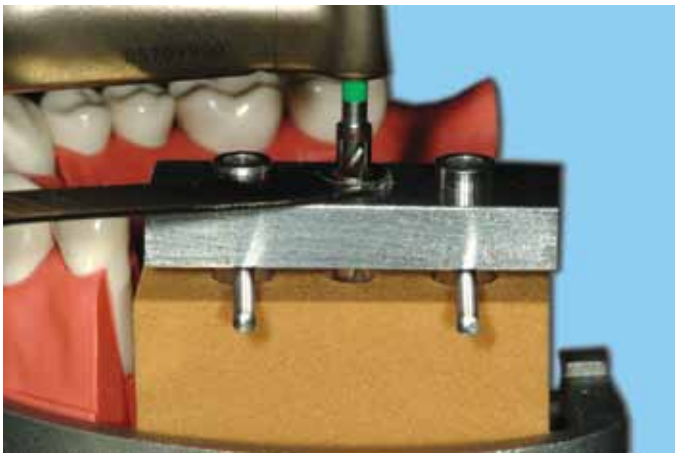
Table I. Descriptive statistics

Method of Implant Placement	Height of Guide	Mean (SD) Maximum			
		Implant Level (mm)	Abutment Level (mm)	Apex (mm)	Angle (Degrees)
Freehand	8 mm	0.38 (0.18) 0.73	0.45 (0.15) 0.73	0.63 (0.35) 1.28	0.04 (0.02) 0.08
	6 mm	0.49 (0.17) 0.80	0.54 (0.19) 0.80	0.61 (0.26) 1.00	0.03 (0.02) 0.07
	4 mm	0.40 (0.18) 0.71	0.55 (0.23) 1.09	0.74 (0.23) 1.13	0.06 (0.02) 0.09
	Average of means	0.43 (0.18)	0.52 (0.19)	0.66 (0.28)	0.04 (0.02)
Guided	8 mm	0.25 (1.00) 0.40	0.28 (0.15) 0.69	0.47 (0.28) 1.05	0.03 (0.02) 0.08
	6 mm	0.26 (0.13) 0.57	0.28 (0.12) 0.49	0.41 (0.24) 0.82	0.03 (0.01) 0.05
	4 mm	0.24 (0.08) 0.37	0.29 (0.12) 0.55	0.37 (0.15) 0.65	0.03 (0.01) 0.06
	Average of means	0.25 (0.10)	0.28 (0.13)	0.42 (0.23)	0.03 (0.01)

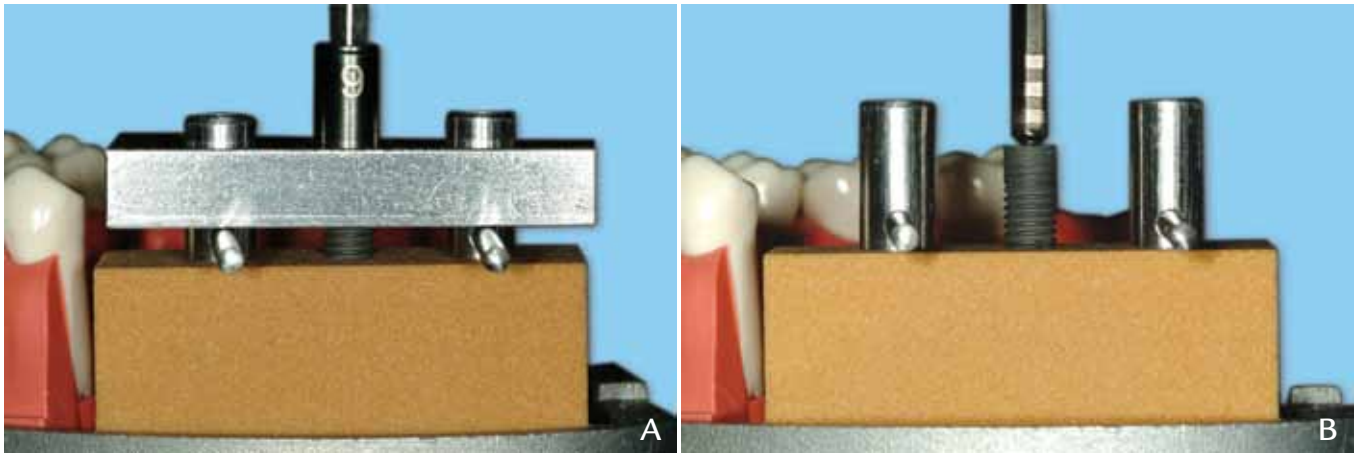
guide was designed to fit this carrier. A metal tube with an internal diameter of 5.5 mm was placed on each vertical beam. Autopolymerizing resin (Pattern Resin; GC America, Inc, Alsip, Ill) was used to connect this metal tube to the implant, which was already assembled to the Facilitate carrier (Fig. 4). The discrepancy from this reference implant to each implant specimen was measured and compared.

One operator followed a standard drilling protocol as recommended by the manufacturer. A round bur and a 2-mm twist drill, a 3.2-mm twist drill, and a 3.7-mm twist drill were sequentially used with the corresponding precision guide sleeves (Fig. 5). Since each drill sleeve was 5 mm in height, only the distance to the bone substitute block varied during drilling. The metal guide itself directed the implant placement; thus, the height of the guide influenced the entire placement phase. Each drill guide insert, 5 mm in height, had a 1-mm-thick metal flange, which was used as a vertical stop. Each

4 Reference implant.



5 Facilitate drill guide used for drilling.



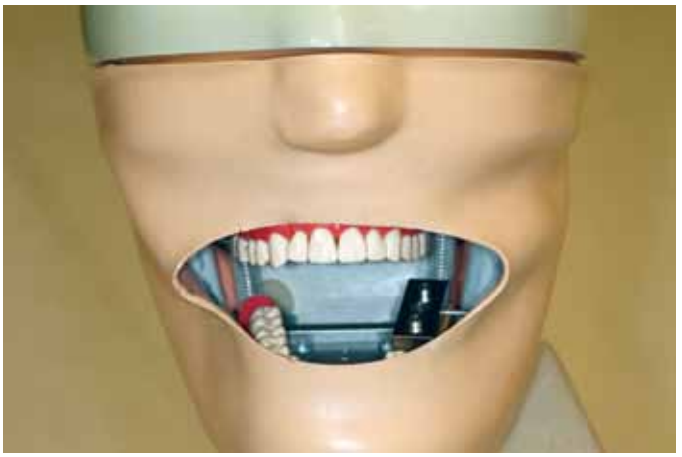
6 A, Guided implant placement with Facilitate implant carrier. B, Freehand implant placement with conventional implant carrier.

set of drills was used for 15 sites and discarded. Vertical depth of drilling for each guide group was preplanned so that the osteotomy finished at the same vertical depth into the bone substitute block for each group of guides. For the 4-, 6-, and 8-mm guide groups, the total length of drilling was 19 mm, 21 mm, and 23 mm, respectively, measuring from the top of the drill guide insert. Drilling was executed at 1500 rpm (WS-75 E/KM contra-angle handpiece, Implantmed motor; W & H Dentalwerk, Bürmoos, Austria). For the guided implant placement group, implant placement was performed through the guides using the implant carrier (Fig. 6, A). For the freehand placement group, the guide was removed after the completion of the osteotomy, and a conventional implant carrier was used to place the implant, with the 2 vertical beams of the metal jig used as direction guides for placement (Fig. 6, B). A torque of 25 Ncm was used for placement. If the motor stopped in the middle of the implant placement procedure, the torque was increased to 35 Ncm, and then a manual wrench was used to complete the placement. All procedures were performed on the manikin to simulate a clinical scenario (Fig. 7).

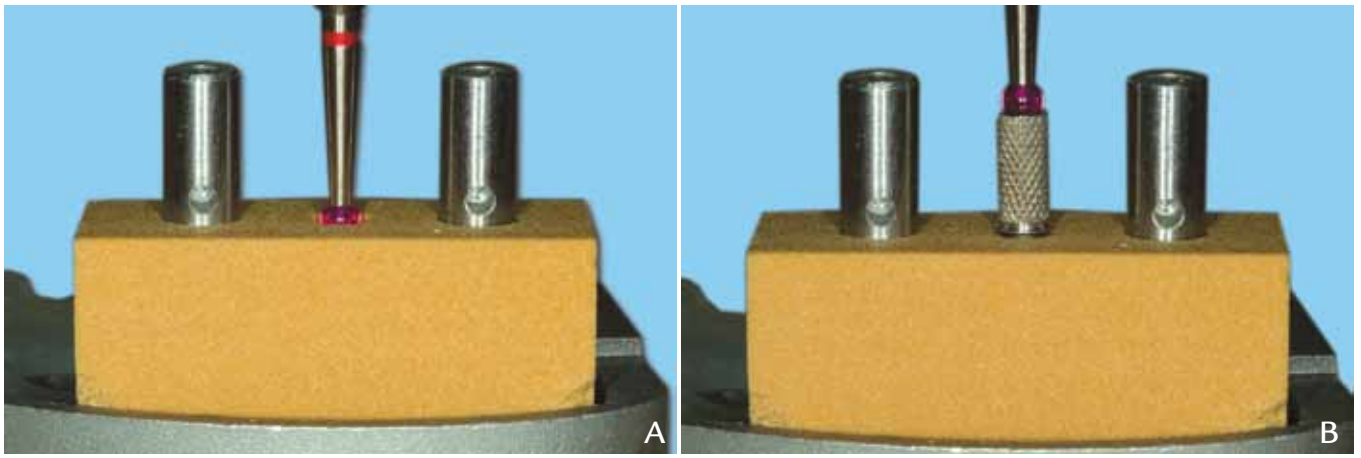
The base of the typodont was fixed with screws to a flat wooden plate, and a coordinate measuring machine (CMM) (Microscribe MX System; Immersion Corp, San Jose, Calif) was fixed to the same plate, so that both were on the same plane. The metal jig was secured to the base of the typodont using light-polymerized composite resin (Triad VLC Custom Tray Material; Dentsply Trubyte, York, Pa). By fixing the typodont and the CMM on the same plane, the metal jig and the CMM had the same spatial relationship throughout the measurements and maintained the same orientation.

The center of the implant was measured at the implant level and abutment level using the CMM, which is accurate to less than 0.002 inches (0.05 mm) (Fig. 8). A sapphire ball probe (Microscribe MX System; Immersion Corp), 3 mm in diameter, was placed on the top of the mesial vertical beam, and this position was set as the customized reference position. The CMM recognized this position as (0, 0, 0) in space. An imaginary line connecting the center of the mesial and distal beam was taken as the x axis (distal direction as +). The right angle to this axis was taken as the y axis (buccal side as + direction). Vertical to this x-y location from the home position was the z axis (occlusal direction as +).

The reference implant block was placed and measured at the implant level. Each measurement was made 5 times and averaged. The same measurement was made after connecting a temporary abutment (Temporary



7 Simulation manikin with attached assembly.



8 A, CMM (Microscribe) used to measure coordinates of implant at implant level. B, Abutment level.

Abutment 3.5/4.0; Astra Tech AB) to the implant. This measurement was used as a reference position, and all other measurements made of the 90 specimens were compared to this position for each implant level and abutment level. The apex and angular discrepancy of the implants were mathematically calculated and compared using the 2 known coordinates of the implant and the abutment. Two-way ANOVA was used for statistical analysis. Level of significance (α) was set to .05 for all of the tests. All calculations were made using a statistical software package (SPSS 12.0; SPSS, Inc, Chicago, Ill).

RESULTS

Descriptive data showed that the mean (SD) and maximum deviation (Max) at the implant level for each of the 4-mm, 6-mm, and 8-mm guided placement groups were 0.24 (0.08) mm, 0.26 (0.13) mm, and 0.25 (0.10) mm, respectively. The average of these means was 0.25 (0.10) mm (Max: 0.57 mm). At the abutment level, they were 0.29 (0.12) mm, 0.28 (0.12) mm, and 0.28 (0.15) mm for each of the 4-mm, 6-mm, and 8-mm guide groups, respectively. The average of these means was 0.28 (0.13) mm (Max: 0.69 mm). At the apex level, the average mean of the 3 guide groups for guided placement was 0.42 (0.23) mm (Max: 1.05 mm). The average mean angular discrepancy of the 3 guide groups for guided placement was 0.03 (0.01) degree. However, for the freehand placement group, the average of the means (SD) of the 3 guide groups and maximum deviation (Max) was 0.43 (0.18) mm (Max: 0.80 mm) at the implant level, 0.52 (0.19) mm (Max: 1.09 mm) at the abutment level, and 0.66 (0.28) mm at the apex level (Max: 1.28 mm) and an average mean angular discrepancy of 0.03(0.02) degrees (Table I). A 2-way ANOVA showed that the placement method, that is, freehand placement versus guided placement, had the greatest influence on accuracy. Significant differences were seen at all aspects of measurement: implant level, abutment level, apex, and angle (P<.001) (Tables II-V). Deviation of the implant for the freehand placement group was significantly higher than for the guided placement group. Guides with different occlusogingival heights (4, 6, and 8 mm) did not result in any significant difference with respect to the accuracy of implant level (P=.196), abutment level (P=.418), apex (P=.728), and angulation (P=.075). Interaction between the 2 variables, height of guide and method of implant placement, was not significant at the implant level, the abutment level, and apex (P=.445, .451, and .264, respectively) (Tables II-IV). However, an interaction was found between the height of the guide and method of implant placement at the angular discrepancy (P=.027) (Table V).

TABLE II. Two-way ANOVA at each aspect of measurement for dependent variable implant

Source	Type III Sum of Squares	*df*	Mean Square	F	*P*
Corrected model	0.817	5	0.163	7.738	<.001
Intercept	10.2	1	10.239	484.634	<.001
Height of guide (H)	0.070	2	0.035	1.661	.196
Method of placement (M)	0.713	1	0.713	33.732	<.001
H x M	0.035	2	0.017	0.818	.445
Error	1.775	84	0.021		
Total	12.831	90			
Corrected total	2.592	89			

TABLE III. Two-way ANOVA at each aspect of measurement for dependent variable abutment

Source	Type III Sum of Squares	*df*	Mean Square	F	*P*
Corrected model	1.3	5	0.258	9.383	<.001
Intercept	14.3	1	14.364	522.680	<.001
Height of guide (H)	0.048	2	0.024	0.881	.418
Method of placement (M)	1.2	1	1.197	43.548	<.001
H x M	0.044	2	0.022	0.803	.451
Error	2.308	84	0.027		
Total	17.962	90			
Corrected total	3.598	89			

TABLE IV. Two-way ANOVA at each aspect of measurement for dependent variable apex

Source	Type III Sum of Squares	*df*	Mean Square	F	*P*
Corrected model	1.554	5	0.311	4.632	.001
Intercept	25.907	1	25.907	386.074	<.001
Height of guide (H)	0.043	2	0.021	0.319	.728
Method of placement (M)	1.329	1	1.329	19.811	<.001
H x M	0.182	2	0.091	1.355	.264
Error	5.637	84	0.067		
Total	33.098	90			
Corrected total	7.191	89			

TABLE V. Two-way ANOVA at each aspect of measurement for dependent variable, angle

Source	Type III Sum of Squares	*df*	Mean Square	F	*P*
Corrected model	0.008	5	0.002	5.696	<.001
Intercept	0.128	1	0.128	485.887	<.001
Height of guide (H)	0.001	2	0.001	2.665	.075
Method of placement (M)	0.004	1	0.004	15.618	<.001
H x M	0.002	2	0.001	3.766	.027
Error	0.022	84	0.000		
Total	0.158	90			
Corrected total	0.030	89			

DISCUSSION

According to the results of this study, the first hypothesis, that the occlusogingival height of the guide does not affect the accuracy of implant placement, was accepted. A 4-mm-high precision surgical guide can be used for implant placement to achieve accuracy similar to that of guides with heights of 6 mm or 8 mm, while gaining more surgical space in the posterior segment for the surgical instruments. The guide with reduced height may be advantageous in posterior partially edentulous scenarios where limited interocclusal space is often encountered.

The second hypothesis, that guided implant placement is as accurate as freehand implant placement, was rejected. In this study, a precise surgical guide enhanced implant placement as planned with a discrepancy of about 0.25 mm or less for the guided placement group and a discrepancy of 0.43 mm or less for the freehand implant placement group at the implant head level. This discrepancy was magnified at the apex. Deviation at the implant level demonstrated that implants were placed within a certain absolute distance calculated from a combination of x, y, and z directions in space. In addition, angular discrepancy, while low, amplified the deviated distance at the apex. The diameter of the surgical guide sleeve had some degree of dimensional difference from that of the implant carrier, allowing slight movement. This movement may have resulted in the 0.25-mm discrepancy for the guided placement group. More importantly, the maximum apical deviation in the guided group was only 1.05 mm, implying improved patient safety with this guide system. For freehand placement, the self-tapping feature of the implant may result in more variation in accuracy. This variation is within the 1-mm range; however, even this small variation may affect results in a clinically significant manner in some situations. A small deviation may be more amplified in actual surgery when managing nonuniform material such as bone, as compared to the uniformly dense plastic bone substitute used in this study. Differences in diameter between the surgical guide and the implant carrier are inevitable. Two metal components must have clearance to avoid excessive friction if the diameters of the 2 components are identical. Clinically, this would result in the binding of components during the implant placement procedure and incomplete seating of the prosthesis. This binding and frictional force could dislodge the guide itself. However, excessive space between components may result in an unacceptable variation in implant position. NobelGuide (Nobel Biocare AB), Facilitate (Astra Tech AB), Navigator (Biomet 3i, Palm Beach Gardens, Fla), and other similar systems build in clearance for these components. Therefore, different systems may result in different levels of accuracy in terms of the implant position. Further studies are required to assess the optimal dimensions of the components used in the guide. Diameter discrepancies between the implant carrier and the channel of the guide may be the key to optimization.

This study showed that the height of the surgical guide may not be a critical factor for accurate implant placement when a precise guide is used. A shorter guide, for example, with a 2-mm occlusogingival height, was not included in this study due to lack of compatibility with the Facilitate system. However, using such a guide may produce interesting results in terms of the amount of guidance needed for accurate implant placement. As the height of the guide is reduced, interaction between the height of the guide and the method of implant placement becomes significant. To maintain a certain range of accuracy in terms of angular discrepancy, there might be a critical guide height which cannot be further reduced without compromising angular accuracy. Design features to maximize surgical space and also maintain the accuracy of implant placement are key factors for the implant surgical guide. Contrary to the results of Choi et al,[35] this study showed that the length of the sleeve or channel did not affect the accuracy of the implant position. This discrepancy may due to the fact that Choi et al used a single sleeve and not incre-

mental drill guides.

In a cadaver study, van Steenberghe et al[32] reported a mean 0.8-mm deviation (Max 1.4 mm) at implant entry level and a mean of 0.9 mm (Max 1.5 mm) at the apex level. The discrepancy in axis was 1.8 degrees (Max 3.8 degrees). In contrast, Vrielinck et al[33] reported a 2.8-mm mean deviation (Max 7.4 mm) at the implant level and a 4.5-mm mean deviation apically (Max 9.7 mm). This considerable gap in values may be attributed to the various study designs. In addition, these types of CT-based evaluations depend on CT resolutions typically not smaller than 0.3 mm. Moreover, all other possible sources of error may affect the results. These include the accuracy of the CT image itself, distortion in the surgical guide fabrication process, positioning errors with the guide, stability during surgery, and inherent error from mechanical component tolerance in the surgical guides. In this study, the mechanical components were separated and evaluated under a controlled environment. A 0.25-mm deviation in the guided placement group is relatively small compared to the other studies. This may not represent the cumulative error of the entire system, but may give important information in terms of surgical guide design from a mechanical standpoint. Clinical application of the data from this study and other related studies should be done based on the clinical situation. Prefabricated provisional single crowns may require slight adjustment when an implant is placed using a precision guide. Prefabricated complete-arch restorations which include multiple implants will be more of a challenge, even though the deviation in position of each individual implant is small.

This study was performed using bone substitute blocks instead of real bone to control the variables. This may limit the direct clinical application of the data from this study. While measuring, the ball probe of the CMM measured the center of the ball probe. When the ball touched the internal space of the implant, it measured a point slightly above the actual center of the implant. Thus, this discrepancy was applied to all implants, including the reference implant; consequently, the calculated linear discrepancy should be a constant.

In many situations, implants are placed without surgical guides. Some implant guide systems are designed to place implants through the guide. However, for many custom-made guides, the surgical guide may be removed during surgery because it interferes with the placement of the implant. This study demonstrated that freehand implant placement, given the same osteotomy, results in less accuracy than that achieved when the implant is guided through the final placement step, only. Clinicians should consider that such a discrepancy may be amplified in true clinical scenarios, as compared to the results of this study. Most of the CAD/CAM surgical guides require a large amount of mouth opening and interocclusal space. The handpiece itself, the implant carrier, the surgical guide, the drill guide, and other components may increase height to the point that these surgical instruments may not be used. To bring CAD/CAM technology to surgical guides for daily practice, the cost-benefit issue should be considered, and an effort should be made to minimize the volume or height of the instrument and guide system.

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:

1. Precision surgical guides with a 4-mm occlusogingival height allow placement as accurate as guides with an 8-mm height, for both the freehand and guided placement groups.

2. Implant placement through the precision surgical guide is more accurate than freehand placement into the guided osteotomy.

REFERENCES

1. Garber DA, Belser UC. Restoration-driven implant placement with restoration-generated site development. Compend Contin Educ Dent 1995;16:796, 798-802, 804.
2. Neidlinger J, Lilien BA, Kalant DC Sr. Surgical implant stent: a design modification and simplified fabrication technique. J Prosthet Dent 1993;69:70-2.
3. Blustein R, Jackson R, Rotskoff K, Coy RE, Godar D. Use of splint material in the placement of implants. Int J Oral Maxillofac Implants 1986;1:47-9.
4. Tarlow JL. Fabrication of an implant surgical stent for the edentulous mandible. J Prosthet Dent 1992;67:217-8.
5. Ku YC, Shen YF. Fabrication of a radiographic and surgical stent for implants with a vacuum former. J Prosthet Dent 2000;83:252-3.
6. Dixon DL, Breeding LC. Surgical guide fabrication for an angled implant. J Prosthet Dent 1996;75:562-5.
7. Engelman MJ, Sorensen JA, Moy P. Optimum placement of osseointegrated implants. J Prosthet Dent 1988;59:467-73.
8. Lee SY, Morgano SM. A diagnostic stent for endosseous implants to improve conventional tomographic radiographs. J Prosthet Dent 1994;71:482-5.
9. Parel SM, Funk JJ. The use and fabrication of a self-retaining surgical guide for controlled implant placement: a technical note. Int J Oral Maxillofac Implants 1991;6:207-10.
10. Akça K, Iplikçioglu H, Cehreli MC. A surgical guide for accurate mesiodistal paralleling of implants in the posterior edentulous mandible. J Prosthet Dent 2002;87:233-5.
11. Sicilia A, Noguerol B, Cobo J, Zabalegui I. Profile surgical template: a systematic approach to precise implant placement. A technical note. Int J Oral Maxillofac Implants 1998;13:109-14.
12. Shotwell JL, Billy EJ, Wang HL, Oh TJ. Implant surgical guide fabrication for partially edentulous patients. J Prosthet Dent 2005;93:294-7.
13. Solow RA. Simplified radiographic-surgical template for placement of multiple, parallel implants. J Prosthet Dent 2001;85:26-9.
14. Burns DR, Crabtree DG, Bell DH. Template for positioning and angulation of intraosseous implants. J Prosthet Dent 1988;60:479-83.
15. Becker CM, Kaiser DA. Surgical guide for dental implant placement. J Prosthet Dent 2000;83:248-51.
16. Atsu SS. A surgical guide for dental implant placement in edentulous posterior regions. J Prosthet Dent 2006;96:129-33.
17. Kopp KC, Koslow AH, Abdo OS. Predictable implant placement with a diagnostic/surgical template and advanced radiographic imaging. J Prosthet Dent 2003;89:611-5.
18. Almog DM, Torrado E, Meitner SW. Fabrication of imaging and surgical guides for dental implants. J Prosthet Dent 2001;85:504-8.
19. Cehreli MC, Calis AC, Sahin S. A dual-purpose guide for optimum placement of dental implants. J Prosthet Dent 2002;88:640-3.

20. Marchack CB. CAD/CAM-guided implant surgery and fabrication of an immediately loaded prosthesis for a partially edentulous patient. J Prosthet Dent 2007;97:389-94.
21. Balshi SF, Wolfinger GJ, Balshi TJ. Guided implant placement and immediate prosthesis delivery using traditional Branemark System abutments: a pilot study of 23 patients. Implant Dent 2008;17:128-35.
22. Ruppin J, Popovic A, Strauss M, Spüntrup E, Steiner A, Stoll C. Evaluation of the accuracy of three different computer-aided surgery systems in dental implantology: optical tracking vs. stereolithographic splint systems. Clin Oral Implants Res 2008;19:709-16.
23. Widmann G, Bale RJ. Accuracy in computer-aided implant surgery--a review. Int J Oral Maxillofac Implants 2006;21:305-13.
24. Wanschitz F, Birkfellner W, Watzinger F, Schopper C, Patruta S, Kainberger F, et al. Evaluation of accuracy of computer-aided intraoperative positioning of endosseous oral implants in the edentulous mandible. Clin Oral Implants Res 2002;13:59-64.
25. Brief J, Edinger D, Hassfeld S, Eggers G. Accuracy of image-guided implantology. Clin Oral Implants Res 2005;16:495-501.
26. Nickenig HJ, 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;35:207-11.
27. Van Assche N, van Steenberghe D, Guerrero ME, Hirsch E, Schutyser F, Quirynen M, et al. Accuracy of implant placement based on pre-surgical planning of three-dimensional cone-beam images: a pilot study. J Clin Periodontol 2007;34:816-21.
28. Tardieu PB, Vrielinck L, Escolano E, Henne M, Tardieu AL. Computer-assisted implant placement: scan template, simplant, surgiguide, and SAFE system. Int J Periodontics Restorative Dent 2007;27:141-9.
29. Holst S, Blatz MB, Eitner S. Precision for computer-guided implant placement: using 3D planning software and fixed intraoral reference points. J Oral Maxillofac Surg 2007;65:393-9.
30. Vercruyssen M, Jacobs R, Van Assche N, van Steenberghe D. The use of CT scan based planning for oral rehabilitation by means of implants and its transfer to the surgical field: a critical review on accuracy. J Oral Rehabil 2008;35:454-74.
31. Sarment DP, Sukovic P, Clinthorne N. Accuracy of implant placement with a stereolithographic surgical guide. Int J Oral Maxillofac Implants 2003;18:571-7.
32. van Steenberghe D, Naert I, Andersson M, Brajnovic I, Van Cleynenbreugel J, Suetens P. A custom template and definitive prosthesis allowing immediate implant loading in the maxilla: a clinical report. Int J Oral Maxillofac Implants 2002;17:663-70.
33. Vrielinck L, Politis C, Schepers S, Pauwels M, Naert I. Image-based planning and clinical validation of zygoma and pterygoid implant placement in patients with severe bone atrophy using customized drill guides. Preliminary results from a prospective clinical follow-up study. Int J Oral Maxillofac Surg 2003;32:7-14.
34. Yong LT, Moy PK. Complications of computer-aided-design/computer-aided-machining-guided (NobelGuide) surgical implant placement: an evaluation of early clinical results. Clin Implant Dent Relat Res 2008;10:123-7.
35. Choi M, Romberg E, Driscoll CF. Effects of varied dimensions of surgical guides on implant angulations. J Prosthet Dent 2004;92:463-9.

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