Comparison of Positioning Accuracy Between 2 Different Implant Systems Using Mucosa-Supported Surgical Templates: A Retrospective Clinical Study

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Although guided implant surgery is widely practiced, clinical studies examining the differences in accuracy between implanting systems that use the same surgical guide are currently lacking. This study aimed to evaluate and compare the effects of different dental implanting systems on positioning accuracy using a uniform type of stereolithographic surgical guide to account for cumulative errors in guide production. One hundred BEGO Semados S implants (group A) and 91 NobelActive implants (group B) were inserted into patients using the same type of guide. The accuracy was assessed by matching the preoperative and postoperative cone-beam computerized tomography. The implant shoulder, tip, depth, and angular deviation were registered. Statistically significant differences between groups were determined using Student *t* test, bivariate correlation test, and generalized estimating equation. The angular deviation was 3.16 ± 1.74° in group A and 2.58 ± 1.41° in group B ($P = .013$); the depth deviation was 0.44 ± 0.23 mm in group A and 0.51 ± 0.22 mm in group B ($P = .032$). In terms of vertical accuracy, the Bego implant system is superior to the Nobel implant system using the same type of surgical guide, while the angle accuracy is opposite. Therefore, it is important to control the depth when using the template-guided surgery with the Nobel implant system. Similarly, angle control should be emphasized in the Bego implant system. Measurements of the deviations provide the basis for a clinical reference that will be useful in preoperative analysis for improving the safety and accuracy of guided implant surgical procedures.

Key Words: accuracy, dental implant, stereolithography, surgical template

INTRODUCTION

Dental implants provide a more natural and comfortable tooth replacement than dentures do. Anatomical variation among patients in the delicate tissue that can be damaged during insertion of implants necessitates the development and improvement of better tools and methods for accurate positioning. With the development of 3-dimensional digital planning technology, stereolithographic (SLA) guides for surgery have become widely used in implant placement.[1–3] Guided surgery provides greater accuracy for surgeons than freehand surgery does.[4] Implants can be more easily inserted in the appropriate position, especially in relation to the nasal cavity, maxillary sinus, mandibular canal, and adjacent teeth. Furthermore, the use of templates can reduce surgery time.[5]

It is important to note that there is always deviation between the virtually planned position of implants and the final position of the inserted implants.[6] D'Haese and colleagues[7] evaluated the placement accuracy of Astra Tech OsseoSpeed dental implants compared with the virtual plans for those implants and found an average angle deviation of 2.60°. Yi Sun and colleagues[8] reported that the average maximum vertical deviation at the implant apex was within 1 mm (0.1–4.6 mm) using NOBELSPEEDY Groovy RP implants. Computer-aided implant surgery involves a series of processes including image acquisition by cone-beam computerized tomography (CBCT), software planning, and manufacture of the surgical template, all of which can produce errors in the plan for the implant.[9–11] However, errors in the insertion can also occur due to limitations in the precision of the SLA machine, the guide cylinders and metal tubes, and the physical properties of the materials.[10,12–14] During surgery, the presence of a rotational allowance in tube-sleeve drills, differences in drill shape (straight or tapered), and drill sharpness can all lead to deviation between the postoperative and virtual positions of

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the implants.[7,9,10,12] These errors accumulate, resulting in potentially serious divergence from the optimal position of insertion, as determined by virtual planning. It is inconvenient and problematic in clinical practice for each implanting system to require a specific or proprietary guide that is incompatible with other systems. A new type of universal guide system has brought considerable convenience to clinical surgery. However, few studies comparing the differences in accuracy between implanting systems have accounted for errors in guide manufacturing by using the same type of surgical guide, designed and fabricated by a single manufacturer, and especially between implants with different shapes (ie, straight or tapered).

The aim of the present study was to evaluate and compare the effects introduced by different implant systems on the accuracy of surgery using a uniform type of template, thus controlling for the accumulation of errors throughout the computer-aided implant placement process. This study examined the postoperative positions of implants from 2 systems that differ in procedural steps and implant shape. Measurements of the deviations in coronal and apical positions, depth, and implant angle provide the basis for a clinical reference that will be useful in preoperative analysis for improvement of the safety and accuracy of guided implant surgical procedures.

Materials and Methods

The study was approved by Research Ethics Committee of the Affiliated Stomatology Hospital of Zhejiang University School of Medicine (ethics approval No. 2017-013).

Patients

This study was a retrospective data collection that did not alter the standard treatment protocols. Included in the study were 34 patients (13 women, 21 men) with a fully edentulous or maxilla or mandible or partially edentulous who required the insertion of at least 4 implants under the guidance of a mucosa-supported template. Among the 34 patients, 12 were fully edentulous, 17 had edentulous arches with fresh extraction sockets, and 5 were partially edentulous. All patients were consecutively treated between 2014 and 2018 in our hospital. Patients with unhealthy systemic health status, uncontrolled diabetes, parafunctional habits, poor oral hygiene, severe alveolar bone deficiencies (eg, requiring a bone for the implant recipient site), current irradiation treatment of the head or neck, psychological disorders, and abuse of alcohol and tobacco (evidence of heavy smoking [>10 cigarettes per day]) were excluded. The patients gave their informed consent for the treatment and for their data to be used for research purposes.

Study groups

In group A, patients was given BEGO Semados S implants (BEGO GmbH & Co, KG, Bremen, Germany), and patients in group B were given NobelActive implants (Nobel Biocare, Zürich, Switzerland).

Table 1

Operational protocol (tool format: drill/clamp)

Implanting System (Diameter)	BEGO (4.1 mm)	Nobel (4.3 mm)
Step 1	Spotting drill/3	Spotting drill/3
Step 2	2.0/3	2.0/3
Step 3	2.8/4	2.8/4
Step 4	3.25/5	
Remove template		
Classification of bone	II–III	II–III

Implant planning

A provisional, immediate, removable denture was fabricated that satisfied both esthetic and functional requirements. For patients already wearing an existing prosthesis, a relining procedure was performed to ensure that the fit was optimal. A radiolucent replica of the removable denture was then produced. A bite index was also taken in centric occlusion to stabilize the radiolucent denture in its correct position. To register the position of the denture in relation to the bone, 2 CBCT scans were taken using a CBCT scanner (NewTom VGi, Sino-Ita International Trading Co, Ltd), and 1 scan was taken of the denture alone. Subsequently, the patient wore the radiolucent denture, and instructions were given to bite in the correct position while a second scan was taken of the patient with the denture. The parameters in the scanner were 110 kV, 8 mA, scanning time of 18 seconds, and voxel size of 0.3 $\times$ 03 $\times$ 0.3 mm. The output data from both scans were exported in digital image communications in medicine (DICOM) format. Using the 2 scans, 3-dimensional reconstructions of the alveolar bone and the radiolucent denture were created using 6D Planning Software (6D Dental Tech Co, Ltd, Hangzhou, China). For each patient, 4 or 6 implants were virtually planned at their optimal location. Fixation pins were planned to stabilize the surgical stand during the operation. Based on the virtual implant plan, a customized surgical template was designed and manufactured by 6D Dental using stereolithography.

Surgery

All implant installations were performed by experienced doctors. The surgical interventions were conducted by the same operator who performed the virtual surgical planning. The surgery was performed under local anesthesia and followed sterile procedures. Before the operation, the bite index was used to assist the surgeon in placement of the template in the same position as the denture during the preoperative CBCT scan. The SLA surgical template was then fixed to the maxilla or mandible with anchor pins, and the bite index was removed.

The surgical procedure was performed according to the operational protocol as follows (Table 1). After positioning, double-bend clamps were used to match each drill in preparation for the increasing diameter of the cavity. A drill stop was used to limit the drilled cavity to the desired depth. The operational protocol of the Nobel system required 1 fewer step than the BEGO system because of the tapered shape. The

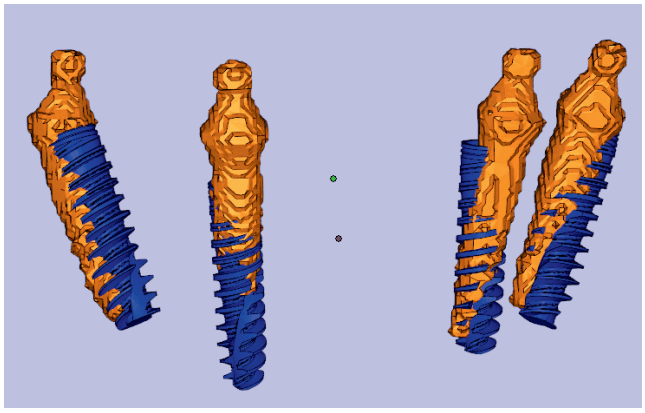

Figure 1. The placed implants were compared with the preoperative surgical plan (yellow indicates the virtual planned position; blue indicates the postoperative position).

guide system with operational tools has received several patents. After template removal, implants were inserted into the maxilla or mandible with NobelActive (or BEGO Semados S) surgery drills, with a torque of 35 Ncm. Immediately after implantation, healing abutments or cover screws were placed.

Postoperatively, each patient received a CBCT scan to determine the position of the implants using the same settings as for the preoperative scan. The postoperative CBCT data were aligned to the preoperative data that were used for virtual implant planning using voxel-based registration.[15] The registered postoperative CBCT data were imported into 6D Dental Planning software in DICOM format. The postoperative implants were segmented, and each implant was then compared with the planned implant position (Figure 1).

Analysis of positioning accuracy

The following implant position parameters were analyzed for deviation from the virtual plan: implant shoulder and tip deviation, angular deviation, and depth deviation. The implant shoulder (or tip) deviation was defined as the 3-dimensional distance between the shoulder (or tip) centers of the planned and placed implants. The depth deviation was the distance between the apical central points of the planned and placed implants. The angular deviation was calculated as the 3-dimensional angle between the longitudinal axis of the planned and placed implants (Figure 2).

Statistics

Statistical analysis was performed with SPSS 22 for Windows computer software (Statistical Package for Social Science, IBM Corporation, Armonk, NY). Comparisons between groups A and B in terms of shoulder, tip, depth, and angular deviation were made using independent-samples *t* tests, after verifying the normality of the distribution of the continuous variables using a Kolmogorov-Smirnov test of normality. Differences were considered statistically significant when the *P* value was $<.05$. Intragroup correlations (ie, by separately analyzing the data in groups A and B) between variables (implant shoulder, tip, depth, and angular deviation) were performed using a bivariate correlation test. Since every patient received multiple implants,

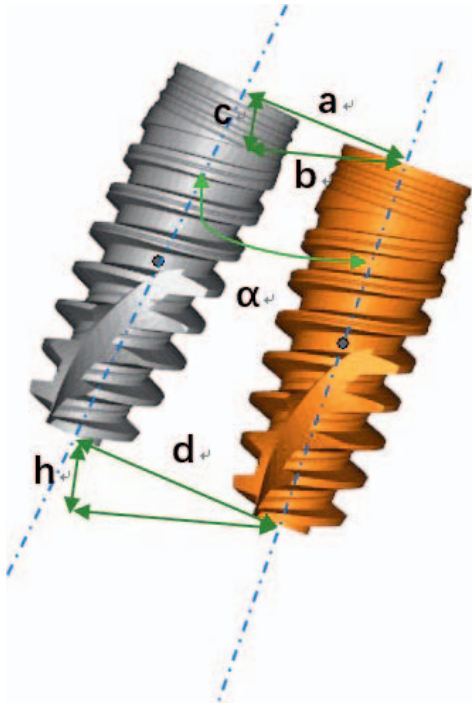

Figure 2. Three-dimensional evaluation of planned (gray) and placed (yellow) implant. α: the angular deviation between planned and placed implant axis; a: the implant shoulder deviation; d: the implant tip deviation; h: the depth deviation.

the data obtained from the same patient were regarded as repeated measurement data. The generalized estimating equation could effectively be used for the intragroup correlation and to obtain the parameters of the central effect. In addition, the effects of confounding factors and their magnitude could be estimated.

The statistical analysis was reviewed by an independent statistician.

Results

Patients and implants

A total of 100 BEGO Semados S implants (BEGO GmbH & Co. KG, Bremen, Germany) were placed in 15 patients for a comparison of accuracy in group A. The population consisted of 7 men and 8 women. The mean patient age was 57.7 years (range, 43–68 years). A total of 91 NobelActive implants (Nobel Biocare) were inserted in 19 patients, including 14 men and 5 women in group B. The mean patient age was 58.4 years (range, 34–77 years).

The patient and treatment characteristics of the 34 adults included in this study, divided in the 2 groups, are summarized in Table 2.

Accuracy

A total of 191 implants were available for comparison of accuracy. The implant (shoulder and tip), depth, and angular deviations were determined. The mean deviations between

TABLE 2

Patient and treatment characteristics

	Total	Group A	Group B
Age, y, mean ± SD		57.3 ± 7.24	57.7 ± 11.1
Number of subjects	34	15	19
Number of implants	191	100	91
Gender (number of subjects/implants)			
Male		7/50	14/71
Female		8/50	5/20
Arch (number of implants)			
Maxilla		52	39
Mandible		48	52

planned and placed implants at the shoulder and apical ends were 0.68 ± 0.24 mm and 0.95 ± 0.3 mm, respectively. The angular deviation was 2.88 ± 1.61°; the depth deviation was 0.47 ± 0.22 mm (Table 3).

In group A, the mean deviations at the shoulder and apical ends were 0.67 ± 0.22 mm and 0.95 ± 0.33 mm, respectively. The angular deviation between the planned and placed implants was 3.16 ± 1.74°; the depth deviation was 0.44 ± 0.23 mm. In group B, the mean deviation in distance was 0.7 ± 0.27 mm at the implant shoulder and 0.96 ± 0.37 mm at the implant tip. The angular deviation between the planned and placed implants was 2.58 ± 1.41°; the depth deviation was 0.51 ± 0.22 mm.

Table 3 shows the frequency distribution and deviation values in the 2 groups. A greater deviation was observed at the implant tip than at the shoulder. No statistically significant differences ($P \geq .05$) were found in the deviation of the implant shoulder ($P = .381$) or deviation of the tip ($P = .755$) between groups A and B. However, significant differences were demonstrated for angular deviation ($P = .013$) and depth deviation ($P = .032$) between the 2 different groups.

Significant correlations were found in both groups between depth and implant tip deviation, depth and implant shoulder deviation, and angular and implant tip deviation. The correlation between depth and implant tip deviation was greater than that between depth and implant shoulder deviation. However, angular deviation was related to implant shoulder deviation in group B but not in group A (Table 4).

Analysis with generalized estimating equations, a common modeling approach used in cluster randomized trials to account for within-cluster correlation, indicated that significant differences were found in depth deviation (Exp.[B] = 1.095; $P = .02$) and angular deviation (Exp.[B] = 0.496; $P = .03$) between the 2 groups, which was consistent with the results of the *t*-test analysis. No statistically significant differences ($P \geq .05$) were found in gender or jaw position (Table 5).

Post hoc calculation

Based on the results, the mean angular deviation in group A was 3.16 ± 1.74° and the angular deviation in group B was 2.58 ± 1.41°. When the level of significance for all statistical tests was set at an alpha of 0.05 and the total sample size was 34 patients, a power of 0.94 was calculated (G*Power version 3.1.9.2 software).

DISCUSSION

Care must be taken in implant placement not to harm anatomical structures. Deviation in implant placement depth and angle may cause critical surgical complications, for example, sinus membrane perforation, nerve injury, and profuse bleeding. Stereolithographic surgical guides could prevent those surgical errors and assist in the implants' immediate loading.[16] However, during the guide fabrication process and surgical procedures, errors may be intervened and accumulated during each step. Several studies have tested the accuracy of implant placement using surgical templates,[7,17,18] although no studies to our knowledge have compared the deviation of different implant systems while using the same surgical guide.

The template we used was a uniform type of SLA surgical guide, which is widely used and is suitable for different implant systems. Here, the use of a pilot-drill guided implant allows clinicians to change the implant position or angulation by guiding the pilot drill, correcting the implant position or angulation due to anatomical requirements or another consideration.[19]

In our study, we summed up the cumulation of all errors, and our report on the accuracy of the different implants system provides useful data for clinical practice. The primary difference between systems was the conical shape of the NobelActive implants as compared with the cylindrical shape of the BEGO Semados S implants. In addition, the apical diameter of the NobelActive implant was smaller, as mentioned in Table 1, and required 1 less operational step than the BEGO Semados S implant did, likely resulting in a smaller sum of errors. In this study, the same type of surgical guide, which accommodated

TABLE 3

Comparison between group A (Bego) and group B (Nobel) with regard to deviation of shoulder, tip, depth, and angular values[†]

	Overall (N = 191)	Group A (n = 100)	Group B (n = 91)	Significance (*P*)
Implant shoulder deviation, mm	0.68 ± 0.24	0.67 ± 0.22	0.70 ± 0.27	.381
Implant tip deviation, mm	0.95 ± 0.35	0.95 ± 0.33	0.96 ± 0.37	.755
Depth deviation, mm	0.47 ± 0.22	0.44 ± 0.23	0.51 ± 0.22	.032*
Angular deviation	2.88 ± 1.61	3.16 ± 1.74	2.58 ± 1.41	.013*

[†] Values are reported as mean ± SD. The *t* test for 2 independent samples was used to compare implant shoulder, tip, depth, and angular deviation values, based on the results of the Kolmogorov-Smirnov normality test. A significant difference was demonstrated for depth deviation and angular deviation between groups A and B.

* Significant difference.

Table 4

Group A and group B separate correlations between depth deviation or angular deviation and implant tip and shoulder deviation, respectively†

	Implant Tip Deviation (Spearman rho)	P	Implant Shoulder Deviation (Spearman rho)	P	Depth Deviation (Spearman rho)	P
Group A						
Depth	.474**	.000	.274**	.006	1.000	
Angular	.402**	.000	.046	.647	.063	.533
Group B						
Depth	.460**	.000	.302**	.004	1.000	
Angular	.486**	.000	.455**	.000	.095	.370

† The Spearman rho correlation between the implant tip and angular or depth deviation was greater than that between the implant shoulder and angular or depth deviation.

* The correlation was significant at a confidence level of 0.01 (2-tailed).

drills through parallel tubes, was used for both treatment groups. Therefore, the effect of the tolerance between sleeve and drill was reflected in both systems. The observed differences in the accuracy of the implant position between systems can contribute to differences in procedural steps or implant shape.

In the present study, the implant coronal and apical deviations were lower than that in the study reported by D'Haese et al.[7] In both groups, a greater mean linear deviation between the planned and the placed positions was observed at the implant tip (0.95 mm and 0.96 mm for groups A and B, respectively) than at the implant shoulder (0.67 mm and 0.7 mm for groups A and B, respectively). This could be explained by the fact that implant guidance is optimal in the coronal region of the implant and deviation gradually increases with distance. Consequently, the correlation between angular and implant tip deviation was greater than that between angular and implant shoulder deviation. In another word, a small deviation at the shoulder results in a much wider apical divergence from the planned position.

Compared with the BEGO Semados S implants, a greater vertical deviation in NobelActive implants was found. The design of the drilling blades could also partially explain this: the NobelActive implant, with its reverse-cutting flutes with drilling blades on the apex, may insert deeper than the BEGO Semados S implants.[20] Reverse-cutting flutes with drilling blades on the apex in the NobelActive implants also enable clinicians to adjust the implant position, which explains the smaller angular deviation.

It is worth mentioning that a space between the sleeve and the drill, which is designed to prevent heating, could create tolerance in the diameter of the cavity. Van Assche and Quirynen[6] measured the angular deviation between the planned and placed implants that arises from the tolerance among the mechanical components of 2 SLA surgical guide systems. A mean angular deviation of 5.4° (SD, 0.4; range, 4.8–6°) was found in Nobel guide (Nobel Biocare, Göteborg, Sweden) and 3.9° (SD, 0.3; range 3.5–4.3°) in Facilitate (Astra Tech AB, Mölndal, Sweden). Koop et al[21] found a maximum of 5.2° angular deviation resulting only from the tolerance between the drill and tube.

Laederach and colleagues[22] examined the accuracy of 4 different systems for guided implant surgery in vitro with their corresponding sleeves: Camlog Guide, Straumann Guided, SIC Guide, and NobelGuide. The axial deviation ranged from 0° (Straumann Guided) to 5.64° (Camlog Guide). In terms of angular deviation, statistically significant differences existed between centric and eccentric drilling in all 4 systems. Although conditions were the same for all systems in the study, the clinical condition was much more complicated, resulting in greater deviation in vivo.

Preoperative and intraoperative factors that affect the accuracy of guided surgery have been described previously.[23] Factors, such as movement of patients, limited mouth opening and visibility, and the correct intraoperative position of the surgical template on the mucosa, also affected surgical outcomes. To identify factors causing disparity between in vitro tests and surgical outcomes, more clinical studies need to be carried out focusing on different variables, such as the movement of patients, misfit of the templates, limited opening of the mouth, impaired visibility, and differences in bone density between sites.[23]

Table 5

Outcomes of generalized estimating equation†

	Implant Shoulder Deviation		Implant Tip Deviation		Depth Deviation		Angular Deviation	
	Exp.(B)	P	Exp.(B)	P	Exp.(B)	P	Exp.(B)	P
Group	1.034	.37	1.035	.60	1.095	.02*	0.496	.03*
Gender	0.995	.89	0.995	.93	0.939	.13	1.83	.05
Jaw position	0.987	.75	0.932	.17	0.987	.71	0.808	.36

† Significant differences were found in depth deviation (Exp.[B] = 1.095; $P = .02$) and angular deviation (Exp.[B] = 0.496; $P = .03$) between the 2 groups, which was consistent with the results of the *t*-test analysis. No statistically significant differences ($P \geq .05$) were found in gender variable or jaw position.

* Significant difference.

Some limitations exist in this study. Although our surgery strictly followed standard procedures, some risk factors affecting implant position, such as the thickness of the mucosa and inconsistencies in bone density, were not recorded. Some researchers[24] have suggested that there were negative correlations between bone density and depth deviations. In addition, there was a positive correlation between mucosal thickness and the global deviation at the implant apex. A prospective study should be designed to control and record the impact of more variables on accuracy and to evaluate risks in the future. In addition, as the accuracy of the mucosa-supported guides is affected by multiple factors, tooth-supported surgical guides between 2 different systems could be designed to verify these findings and further clarify the specific clinical variables that contribute to inaccuracies in postoperative implant position.

Conclusions

The accuracy and predictability of computer-aided implant surgery depends on the management of preoperative and intraoperative steps.[25] The uniform type of SLA surgical guide has controllable precision and good adaptability that is suitable for different implant systems. It is important to control the depth when using the template-guided surgery in the Nobel implant system. Similarly, angle control should be emphasized in the Bego implant system.

Abbreviations

CBCT: cone-beam computerized tomography
DICOM: digital image communications in medicine
SLA: stereolithographic

Acknowledgments

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Note

The authors declare no conflict of interests.

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