Check for updates

https://doi.org/10.4047/jap.2023.15.5.259

Reliability of a chairside CAD-CAM surgical guide for dental implant surgery on the anterior maxilla: An *in vitro* study

Phyo Ei Ei Htay[1], Richard Leesungbok[2]*, Suk Won Lee[2], Yu-Jin Jee[3], Kyung Lhi Kang[4], Sung Ok Hong[3]

[1]Department of Prosthodontics, College of Dentistry, Kyung Hee University, Seoul, Republic of Korea
[2]Department of Biomaterials and Prosthodontics, Kyung Hee University College of Dentistry, Kyung Hee University Dental Hospital at Gangdong, Seoul, Republic of Korea
[3]Department of Oral and Maxillofacial Surgery, Kyung Hee University College of Dentistry, Kyung Hee University Dental Hospital at Gangdong, Seoul, Republic of Korea
[4]Department of Periodontics, Kyung Hee University College of Dentistry, Kyung Hee University Dental Hospital at Gangdong, Seoul, Republic of Korea

ORCID
Phyo Ei Ei Htay
https://orcid.org/0009-0005-8271-6049
Richard Leesungbok
https://orcid.org/0000-0002-8381-723X
Suk Won Lee
https://orcid.org/0000-0003-2726-3567
Yu-Jin Jee
https://orcid.org/0000-0003-2526-4005
Kyung Lhi Kang
https://orcid.org/0000-0002-0511-5742
Sung Ok Hong
https://orcid.org/0000-0001-9975-8177

PURPOSE. This study evaluated the reliability of the chair-side CAD-CAM surgical guide (CSG) in the anterior maxilla by comparing its accuracy with the laboratory 3D-printed surgical guide (3DSG) and manual surgical guide (MSG) concerning different levels of dentists' surgical experience. **MATERIALS AND METHODS.** Ten surgical guides of each type (MSG, 3DSG, and CSG) were fabricated on a control study model with missing right and left central incisors. Sixty implants were placed in 30 study models by two dentists (one inexperienced and one experienced) using three different types of surgical guides. Horizontal deviations at shoulder and at apex, vertical, and angular deviations were measured after superimposing the planned and placed implant positions in the software. Kruskal-Wallis and Mann-Whitney U tests were used to compare the accuracy of three types of surgical guides in each dentist group and the accuracy of each surgical guide between two dentists ($\alpha = .05$). **RESULTS.** There were no significant differences in any deviations between CSG and 3DSG, apart from angular deviation, for both dentists' groups. Moreover, both CSG and 3DSG showed no significant differences in accuracy between the two dentists ($P > .05$). In contrast, MSG demonstrated significant differences from CSG and 3DSG and a significant difference in accuracy between the two dentists ($P < .05$). **CONCLUSION.** CSG provides superior accuracy to MSG in implant placement in the maxillary anterior region and is comparable to 3DSG at different levels of surgical experience, while offering the benefits of shorter manufacturing time and reduced patient visits. [J Adv Prosthodont 2023;15:259-70]

KEYWORDS
Dental implant; Accuracy; CAD-CAM; Surgical guide; Computer-assisted implant surgery

Corresponding author
Richard Leesungbok
Department of Biomaterials and Prosthodontics, Kyung Hee University College of Dentistry, Kyung Hee University Dental Hospital at Gangdong, 892 Dongnam-ro, Gangdong-gu, Seoul 05278, Republic of Korea
Tel +8224407520
E-mail lsb@khu.ac.kr

Received July 11, 2023 / **Last Revision** October 20, 2023 / **Accepted** October 25, 2023

https://doi.org/10.4047/jap.2023.15.5.259

INTRODUCTION

Dental implant has undergone significant advances and is now considered a routine dental procedure for the rehabilitation of edentulous areas.[1,2] Proper positioning of implants in three dimensions is crucial for the long-term success of implants. Ideal implant positioning facilitates a highly esthetic prosthesis design, allows proper oral hygiene, and generates a favorable occlusal load.[3-6] This is particularly important in the maxillary anterior esthetic region, where patient expectations of esthetic outcomes are high.[4]

Top-down[7] or restoration-driven approach[8] is an effective method to achieve an ideal implant position. It involves designing the appropriate prosthesis first based on factors such as esthetics, functional occlusion, and oral hygiene, and subsequently placing implants according to this prosthesis design.[7-9]

Implant surgical guides play a pivotal role in the restoration-driven approach by transferring the intended implant positions, which are based on the desired prosthesis designs, to the surgical site.[10] In the 1980s, manually fabricated surgical guides were initially developed.[11-14] However, manual surgical guides offer only a limited guarantee for the initial pilot drill and can lead to significant three-dimensional deviations.[10,15]

In recent years, computer-assisted surgical guides have advanced alongside the development of technology, such as cone beam computed tomography (CBCT), and computer-aided design and computer-aided manufacturing (CAD-CAM) systems.[16,17] In the CAD-CAM surgical guide system, the most appropriate implant position, considering prosthetic and anatomical factors, can be virtually planned in implant planning software, and the CAD-CAM surgical guide is fabricated using additive 3D printing or subtractive milling methods to transfer predetermined virtual implant positions to the surgical site.[18-21] These CAD-CAM surgical guides can provide precise implant positioning and reduce the need for extensive experience.[22,23]

However, the fabrication of CAD-CAM surgical guides is time-consuming and involves several intricate steps. These steps include model scanning or intraoral scanning, CBCT imaging, implant position planning using implant planning software, communication with laboratory staff, and the production, polishing, and finishing of the surgical guides. Because it requires a lengthy diagnostic, planning, and fabrication procedures, taking up to 45% more time than manually fabricated surgical guides, a single patient visit is insufficient for computer-assisted implant surgery.[24]

To address this issue, a novel chairside CAD-CAM surgical guide (CSG) system called VARO Guide (VARO Guide®, NeoBiotech, Seoul, Korea) has been introduced. The "Pre-Guide" (NeoBiotech, Seoul, Korea), a prefabricated resin tray containing light-cured composite resin, is a key feature of this surgical guide system. The "Pre-Guide" serves multiple functions, such as recording the edentulous and surrounding areas, acting as a radiographic stent during CBCT imaging, and ultimately transforming into a static CAD-CAM surgical guide after planning the implant position using VARO Plan software (NeoBiotech, Seoul, Korea) and milling it with a VARO milling machine (NeoBiotech, Seoul, Korea). Due to its innovative manufacturing design, all procedures of implant planning, surgical guide production, and computer-assisted implant surgery can be completed in the dental office during a single visit without requiring optical scanning or laboratory work.[25,26]

To the best of our knowledge, studies are still scarce that demonstrate how the accuracy and experience demands of this chair-side CAD-CAM surgical guide compare to those of other CAD-CAM surgical guides.[26] Therefore, this study aimed to evaluate the reliability of the CAD-CAM CSG by comparing the accuracy of the CSG with a laboratory 3D-printed surgical guide (3DSG) and a manual surgical guide (MSG) in the maxillary anterior esthetic region concerning the different levels of dental implant surgical experience of dentists. The null hypothesis was that the accuracy of implant placement using MSG, 3DSG, and CSG would not differ significantly, irrespective of the dentist's level of experience.

MATERIALS AND METHODS

Two dentists, one with more than 15 years of experience in implant surgery and the other with no experience after graduating from dental school, participated in the study.

A partially edentulous maxillary stone model with adequate bone width and height but missing the right and left central incisors was scanned using an extraoral laboratory scanner (MEDIT T710; MEDIT Corp., Seoul, Korea). Subsequently, 31 resin study models were printed by using a professional Liquid Crystal Display (LCD) 3D printer (Ka:rv LP 550; Shinwon Dental, Seoul, Korea) with an ivory-colored 3D printing resin (Ka:rv Model Resin; Shinwon Dental, Seoul, Korea). The study models were created to mimic the characteristics of D2 bone, which includes porous cortical and coarse trabecular bone, according to the Misch's bone density classification[27] in the edentulous area (Fig. 1).

One study model was used as a control model, in which three different types of surgical guides were fabricated. The remaining 30 models were used as experimental models for implant placement and randomly divided into six groups (Fig. 2).

A radiographic stent was made using clear acrylic resin. Radiopaque markers were placed using 1 mm diameter gutta percha balls so that the images could be superimposed afterwards. After placing the radiographic stent on the control model, CBCT was performed using a CBCT scanner (Carestream CS 9600; Carestream dental, Atlanta, GA, USA) with parameters of 5 mA and 120 kVp, 12 s exposure time, 160 × 100 field of view (FOV), 0.3 mm voxel size, and stored as a Digital Imaging and Communications in Medicine (DICOM) file.

Fig. 1. 3D-printed study models. (A) and (B) 3D-printed resin models. (C) Cross-sectional CBCT image of resin model.

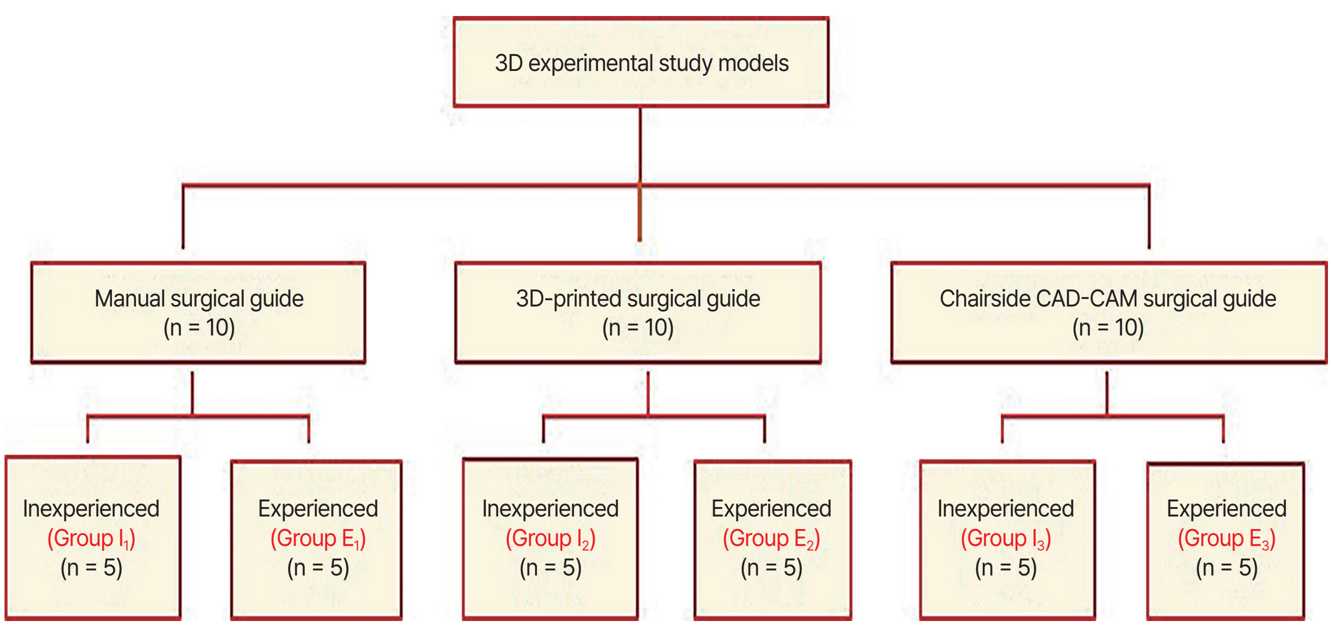

Fig. 2. Distribution of the experimental models.

 https://doi.org/10.4047/jap.2023.15.5.259

The control model was scanned using the same extraoral laboratory 3D scanner (MEDIT T710; MEDIT Corp., Seoul, Korea), and stored as a Standard Tessellation Language (STL) file.

CBCT and 3D scan data of the control model were loaded into the DentiqGuide planning software (DentiqGuide, v.1.3.05; 3DII, Seoul, Korea), and ideal positions of implants were planned. It was used not only for the fabrication of CAD-CAM surgical guides, but also for later measurements of deviations.

In order to fabricate MSGs, the missing central incisors were waxed up on the control model. Then, MSGs were fabricated using a 1.5 mm thickness clear thermo-plastic gasket (Easy-VAC GASKET; 3A MEDES, Seoul, Korea) with a Drufomat Te thermoforming unit (Dreve Dentamid GmbH, Unna, Germany). Drill holes were created in the MSGs at the cingula of the central incisors using a round bur (Fig. 3A).

Ten 3DSGs were fabricated with a 3D printer (Cara Print 4.0; Kulzer GmbH, South Bend, IN, USA) using a 3D printing resin (SG; ODS, Incheon, Korea) according to the planned implant positions (Fig. 3B).

Ten CSGs were fabricated using "Pre-Guides" for the anterior region (PGA) (NeoBiotech, Seoul, Korea), which are made of dimethacrylate and diurethane and filled with composite resin. The "Pre-Guide" was located on the control model, and then the resin was cured with a light-cured unit (Demi^{TM} Plus; Kerr, Brea, Califonia, USA) according to the manufacturer's recommendations. After repositioning the "Pre-Guide" on the control model, a CBCT scan was performed using the same CBCT scanner and parameters as those mentioned above, and the resulting DICOM file was loaded into the VARO Plan software (NeoBiotech, Seoul, Korea). Subsequently, the DICOM data was superimposed on the STL file of the "Pre-Guide", which already existed in the software. The drill holes were milled on the "Pre-Guides" according to the planned implant positions after they had been located on the VARO milling machine (NeoBiotech, Seoul, Korea). Finally, the "Pre-Guides" were ready to be used as the CSG (VARO Guide) (Fig. 3C).

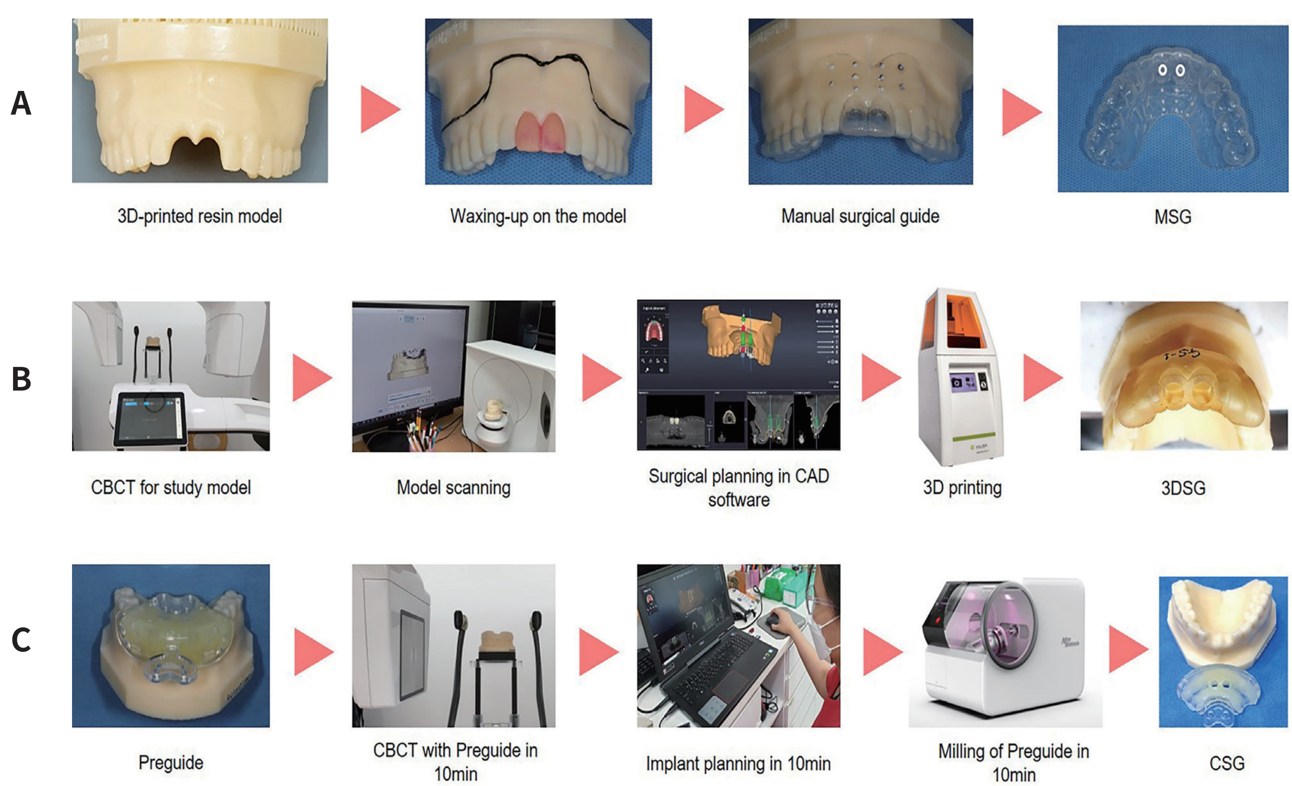

Fig. 3. Fabrication process of 3 types of surgical guides. (A) Fabrication process of manual surgical guide. (B) Fabrication process of 3D-printed surgical guide. (C) Fabrication process of chairside CAD-CAM surgical guide.
MSG: manual surgical guide; 3DSG: 3D-printed surgical guide; CSG: chairside CAD-CAM surgical guide.

Each dentist inserted 30 bone-level implant fixtures of 4.0 × 10 mm (CMI IS III active implants; NeoBiotech, Seoul, Korea), placing two implants in each experimental model and five experimental models for each group after ensuring the proper seating of the respective surgical guides. For the MSG groups, a pilot drill-guided surgery was performed, i.e., MSGs were used only for pilot drilling, followed by serial drilling and implant insertion without surgical guides using an implant surgical kit (NeoSurgical KIT; NeoBiotech, Seoul, Korea). In contrast, fully guided surgery was performed in both the 3DSG and CSG groups using these guides from pilot drilling to implant placement with an implant surgical kit (VARO Guide Kit; NeoBiotech, Seoul, Korea).

After the implants were placed, a second CBCT scan was performed on all experimental models with implants using the same device and settings as before. To prevent bias, an independent investigator who was provided only reference numbers conducted the accuracy analysis.

Placed and planned implant positions were superimposed using DentiqGuide planning software (DentiqGuide, v.1.3.05; 3DII, Seoul, Korea). The four deviation parameters were measured using a software tool (Fig. 4). To evaluate the horizontal deviations at shoulder, the lateral distance between the centers of the shoulder margins of the placed and planned implant positions was measured. For horizontal deviation at apex, the lateral distance between the centers of the apical margins of the placed and planned implant positions at the apex of the implants was measured. The vertical deviation was evaluated by measuring the longitudinal distance between the centers of the shoulder margins in the placed and planned implant positions. Negative values indicated that the shoulder margins of the placed implants were coronal to the planned positions, while positive values indicated that the placed implants were apical to the planned positions. The angle between the centers of the long axes of the two implant positions was measured to determine the angular deviation.

The sample size was calculated using G*Power software (version 3.1.9.7; Kiel University, Kiel, Germany), with an alpha error of 0.05, a statistical power of 80%, and an effect size of 0.6 after the pilot study. Consequently, the sample size calculation revealed that 10 implants (5 experimental models) would be necessary for each group.

Statistical analyses were performed with SPSS software (IBM SPSS Statistic for Windows, version 28.0; IBM Corp., Armonk, NY, USA). The Shapiro-Wilk test was performed to confirm the normality of the distribution of the deviation parameters. The Kruskal-Wallis test was utilized to identify statistically significant differences among the three types of surgical guides for all deviations. If there was a significant difference, a pairwise comparison of surgical guides was performed with Dunn's post hoc test and adjusted by the Bonferroni correction for multiple tests. Furthermore, the Mann-Whitney U test was used to compare the accuracy of each type of surgical guide between the two dentist groups. Statistical significance was set at $P < .05$.

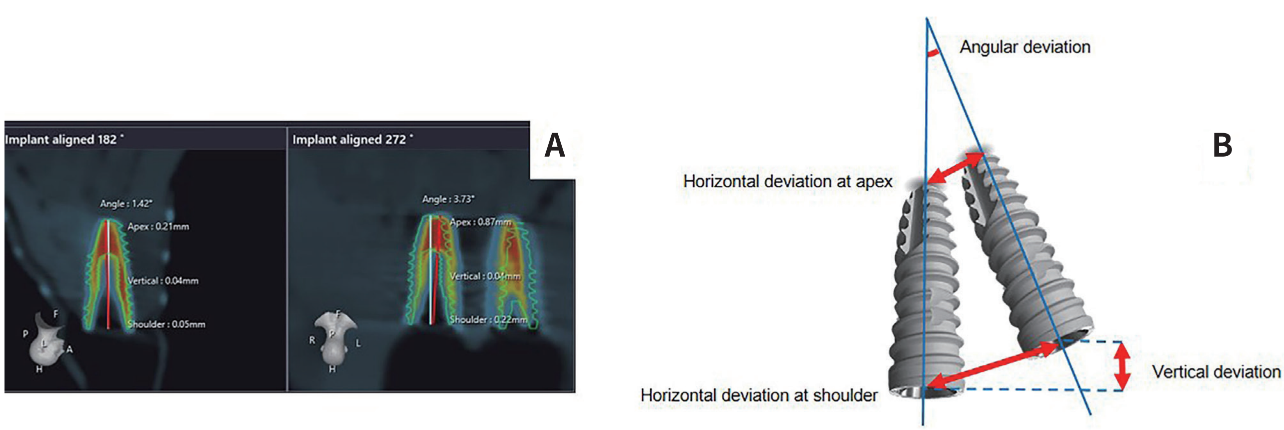

Fig. 4. Measurements of four parameters of deviation. (A) Measurements of four deviations in CAD software. (B) Diagram of measurement of four deviations.

https://doi.org/10.4047/jap.2023.15.5.259

RESULTS

A total of 60 implants were placed by two dentists (one inexperienced and one experienced) utilizing three different types of surgical guides (MSG, 3DSG, and CSG). An analysis of the accuracy of the surgical guides for both inexperienced and experienced dentists is illustrated in Table 1, and Figures 5 and 6, respectively.

For both inexperienced and experienced dentists, there were no statistically significant differences between 3DSG and CSG in all deviations ($P > .05$), apart from the angular deviation ($P < .05$). Meanwhile, MSG was significantly different from 3DSG in all deviations ($P < .05$), and from CSG in the horizontal deviation at apex, vertical deviation, and angular deviation ($P < .05$) for both dentists.

When comparing the performance of the inexperienced and experienced dentists, the experienced dentist outperformed the inexperienced dentist in all deviation variants, regardless of the surgical guide. Significant differences in the horizontal deviation at apex and angular deviation were identified when MSG was utilized ($P < .05$). However, none of the deviations exhibited significant differences between the two dentists when using 3DSG and CSG ($P > .05$), except for the angular deviation ($P < .05$) (Table 2 and Fig. 7).

DISCUSSION

This study assessed the accuracy of three different types of surgical guides, each used by two dentists with different levels of experience by measuring the horizontal deviations at shoulder and at apex, vertical deviation, and angular deviation. The null hypothesis that there would be no significant difference in the accuracy of implant positions among MSG, 3DSG, and CSG, regardless of the dentist's experience level was rejected.

In this study, the 3DSG demonstrated the highest level of accuracy in all deviations for both inexperienced and experienced dentists, and the results are consistent with previous studies.[28-30] These results also fall within the range of average deviations reported in a systematic review by Tahmaseb *et al*.,[31] which meta-analyzed 20 clinical trial studies and revealed the mean deviations of 1.2 mm and 1.4 mm at the shoulder and apex, respectively, and 3.5° angular deviation in computer-assisted implant surgery.

The CSG displayed slightly larger deviations than the 3DSG; nonetheless, these differences were not significant in all deviations for both dentists. These outcomes are in line with a previous study conducted by Song *et al*.,[26] which compared CSG with another CAD-CAM surgical guide (NAVI Guide) in relation to the experience levels of surgeons in the posterior region.

Table 1. Comparison of mean and standard deviations of three different types of surgical guide in four deviations for inexperienced and experienced dentists

Deviations	Experience level	Mean ± Standard deviation			Kruskal-Wallis
		MSG	3DSG	CSG	*P* value
Horizontal deviations at shoulder (mm)	Inexperienced dentist	1.15 ± 0.15	0.66 ± 0.35	0.92 ± 0.29	.005*
	Experienced dentist	0.96 ± 0.26	0.57 ± 0.26	0.91 ± 0.39	.02*
Horizontal deviations at apex (mm)	Inexperienced dentist	3.41 ± 0.43	1.10 ± 0.22	1.18 ± 0.39	< .001*
	Experienced dentist	2.25 ± 0.33	1.17 ± 0.16	1.41 ± 0.40	< .001*
Vertical deviations† (mm)	Inexperienced dentist	1.14 ± 0.15	-0.39 ± 0.30	-0.45 ± 0.17	< .001*
	Experienced dentist	0.94 ± 0.25	-0.25 ± 0.18	-0.29 ± 0.22	< .001*
Angular deviations (degree)	Inexperienced dentist	15.84 ± 0.34	3.02 ± 0.41	7.78 ± 3.13	< .001*
	Experienced dentist	11.75 ± 0.67	1.47 ± 0.33	3.50 ± 1.19	< .001*

MSG, manual surgical guide; 3DSG, 3D-printed surgical guide; CSG, chairside CAD-CAM surgical guide.
*Significant difference at $P < .05$.
† In vertical deviation, positive values mean the shoulder margins of the placed implants are apical to that of the planned implants; negative values mean the shoulder margins of the placed implants are coronal to that of the planned implants.

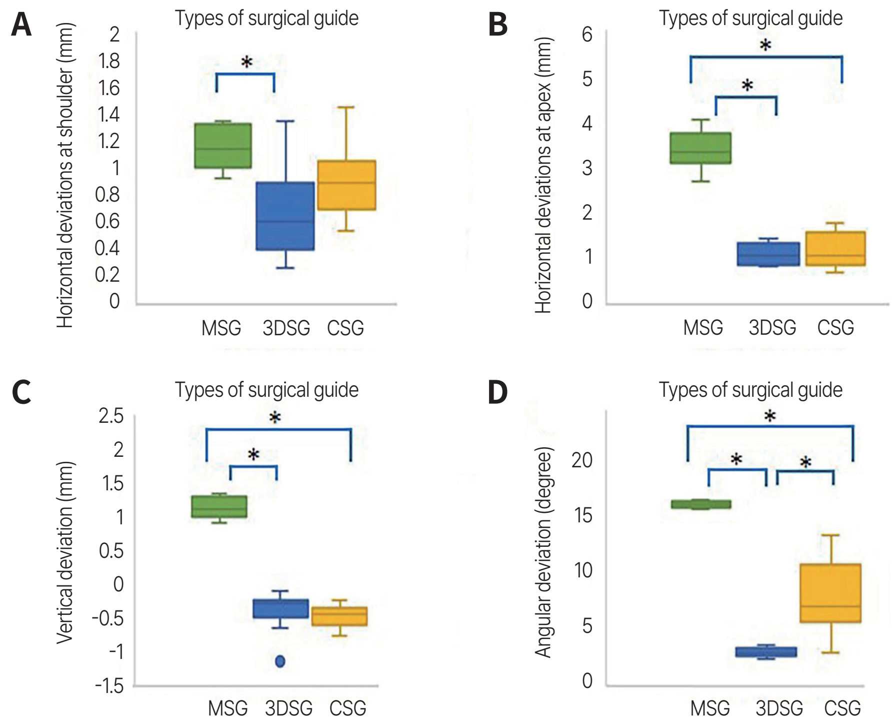

Fig. 5. Box plots of four deviations in relation to the different types of surgical guide for inexperienced dentist. (A) Horizontal deviations at shoulder. (B) Horizontal deviation at apex. (C) Vertical deviation (Positive values mean the shoulder margins of the placed implants are apical to that of the planned implants; negative values mean the shoulder margins of the placed implants are coronal to that of the planned implants). (D) Angular deviation. MSG: manual surgical guide; 3DSG: 3D-printed surgical guide; CSG: chairside CAD-CAM surgical guide. * Significant difference at $P < .05$.

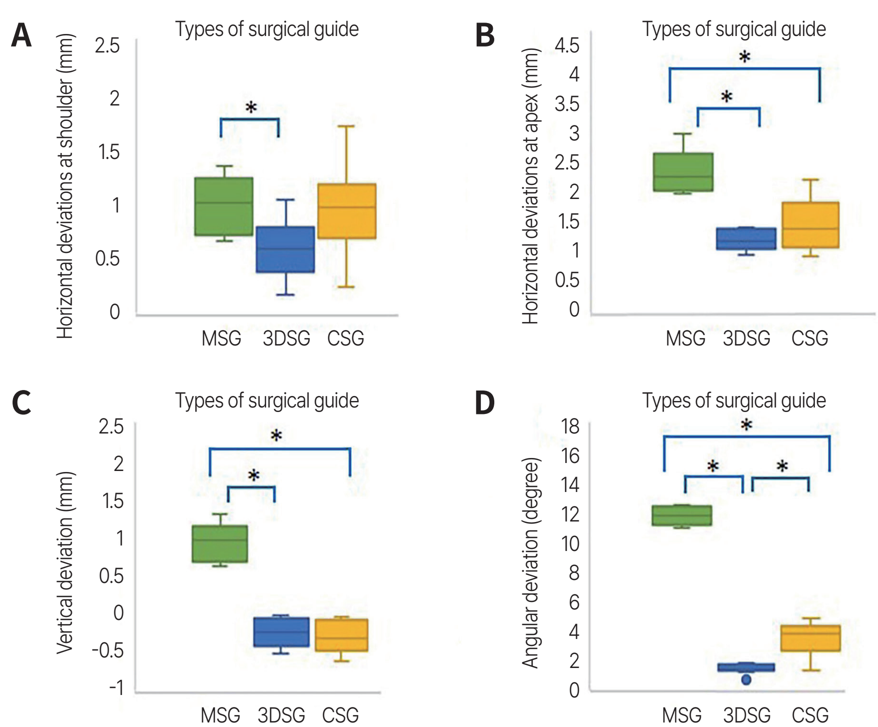

Fig. 6. Box plots of four deviations in relation to the different types of surgical guides for the experienced dentist. (A) Horizontal deviations at shoulder. (B) Horizontal deviation at apex. (C) Vertical deviation (Positive values mean the shoulder margins of the placed implants are apical to that of the planned implants; negative values mean the shoulder margins of the placed implants are coronal to that of the planned implants). (D) Angular deviation. MSG: manual surgical guide; 3DSG: 3D-printed surgical guide; CSG: chairside CAD-CAM surgical guide. * Significant difference at $P < .05$.

https://doi.org/10.4047/jap.2023.15.5.259

Table 2. Comparison of accuracy of each surgical guide in four deviations between the inexperienced and experienced dentists

Deviations	Types of surgical guide	Mean ± SD between Planned and Placed implants		P value
		Inexperienced dentist (n = 10)	Experienced dentist (n = 10)	
Horizontal deviation at shoulder (mm)	MSG	1.15 ± 0.15	0.96 ± 0.26	.09
	3DSG	0.66 ± 0.35	0.57 ± 0.26	.76
	CSG	0.92 ± 0.3	0.91 ± 0.39	.94
Horizontal deviation at apex (mm)	MSG	3.41 ± 0.43	2.25 ± 0.33	< .001*
	3DSG	1.097 ± 0.22	1.17 ± 0.16	.33
	CSG	1.18 ± 0.39	1.41 ± 0.4	.20
Vertical deviation† (mm)	MSG	1.14 ± 0.15	0.94 ± 0.25	.07
	3DSG	-0.39 ± 0.3	-0.25 ± 0.18	.27
	CSG	-0.45 ± 0.17	-0.29 ± 0.22	.10
Angular deviation (degree)	MSG	15.84 ± 0.33	11.75 ± 0.67	< .001*
	3DSG	3.02 ± 0.41	1.47 ± 0.33	< .001*
	CSG	7.78 ± 3.13	3.5 ± 1.19	.002*

SD: standard deviation; MSG: manual surgical guide; 3DSG: 3D-printed surgical guide; CSG: chairside CAD-CAM surgical guide.
* Statistically significant difference in Mann-Whitney U test, *$P < .05$.
† In vertical deviation, positive values mean the shoulder margins of the placed implants are apical to that of the planned implants; negative values mean the shoulder margins of the placed implants are coronal to that of the planned implants.

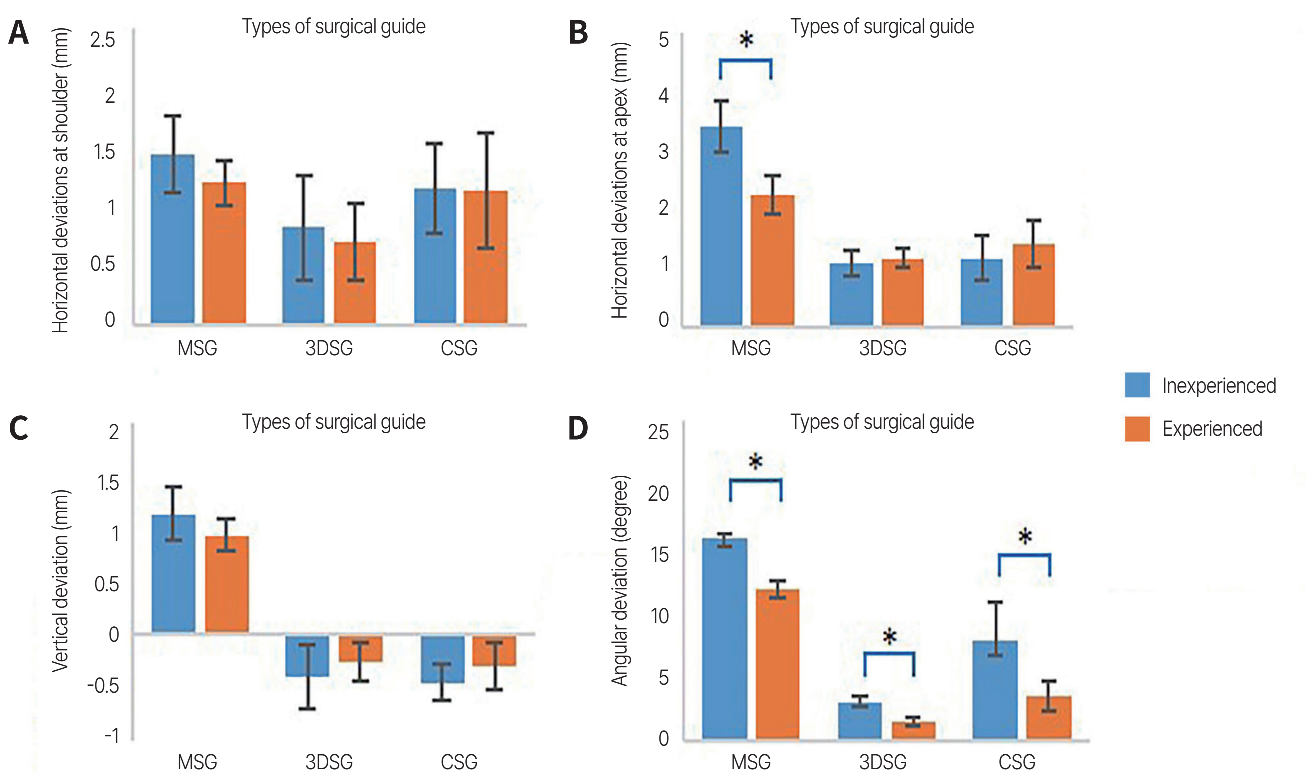

Fig. 7. Comparison of mean deviations between inexperienced and experienced dentists in relation to the different types of surgical guide. (A) Horizontal deviations at shoulder. (B) Horizontal deviation at apex. (C) Vertical deviation (Positive values mean the shoulder margins of the placed implants are apical to that of the planned implants; negative values mean the shoulder margins of the placed implants are coronal to that of the planned implants). (D) Angular deviation. MSG: manual surgical guide; 3DSG: 3D-printed surgical guide; CSG: chairside CAD-CAM surgical guide.
* Significant difference at $P < .05$.

In contrast, the MSG showed significant differences from both computer-assisted surgical guides for each dentist, indicating the highest deviations for all parameters. These results are in accordance with other studies.[15,32,33]

Furthermore, when the two dentists with different levels of experience were compared, the MSG also exhibited significant differences in the horizontal deviation at apex and angular deviation, with the experienced dentist showing superior results.

In contrast, both the 3DSG and CSG did not show significant differences between the two dentists in terms of horizontal deviations at shoulder and at apex, and vertical deviations. Park *et al*.,[23] Song *et al*.,[26] and Rungcharassaeng *et al*.[34] also reported that the impact of surgeon experience on implant placement accuracy was less pronounced when the computer-assisted surgical guides were used.

However, in this study, the angular deviations of both the two computer-assisted surgical guides were significantly different between the two dentists. This is consistent with a previous study by Cushen *et al*.,[35] in which they performed *in vitro* implant placements with stereolithographic surgical guides and compared implant placement accuracy across experience levels. However, they found significant differences not only in the angular deviation, but also in the horizontal deviations at the shoulder and apex.

The 3DSG revealed mean angular deviations of 3.02 ± 0.41° and 1.47 ± 0.33° for the inexperienced dentist and experienced dentist, respectively, while the CAD-CAM CSG showed mean angular deviations of 7.78 ± 3.13° and 3.5 ± 1.19° for the inexperienced and experienced dentists, respectively. The angular deviation of the CSG is consistent with those of static surgical guides used by inexperienced and experienced surgeons in an *in vitro* study done by Wang *et al*..[36] In addition, Furhauser *et al*.[37] conducted a clinical study on flapless implant placements in the maxillary anterior region to investigate the association between the accuracy of computer-assisted surgical guides and esthetic outcomes. They reported that a computer-assisted surgical guide generated angular deviations of up to 12.7°. Therefore, the angular deviations of both 3DSG and CSG in the present study may be considered acceptable as they fall within the clinically acceptable range.

In this study, all implants placed using 3DSG and CSG had shoulder margins coronal to the planned position, regardless of the dentist's experience level. This finding is in agreement with that of a recent randomized clinical trial study performed by Singthong *et al*.,[38] in which computer-aided surgical guides fabricated with two different planning software programs were applied for each group of 12 patients. In both groups, the shoulder margins of the placed implants deviated coronal to that of the planned positions. Another prospective study by Verhamme *et al*.[39] reported that 74% of the implants placed with computer-assisted surgical guides were ≥ 0.5 mm coronal to the planned position. Possible reasons for this deviation could include the misfit of surgical guides and the accumulation of debris in the drilled socket due to the limitation of irrigation at the surgical site during implant surgery. Therefore, it may be prudent to consider the possibility that the implant shoulder deviates coronal to the planned position when placing the implants with computer-assisted surgical guides.

Conversely, both dentists showed positive values of the vertical deviation when using MSGs, indicating that the implants were placed more apical to the planned position. This may be because serial drilling and implant placements were performed without surgical guides in these groups, which allowed the implant shoulder margin to be visible during placement. In the MSG groups, the labial and lingual sides of the implant shoulder margins may not have been at the same level due to large deviations. Moreover, because both dentists attempted to place the entire shoulder margin slightly apical to the alveolar crest, the implant may have deviated more apically from the planned position.

It is undeniable that computer-assisted surgical guides using advanced technologies can reduce deviations. Nevertheless, they are still prone to errors, even for skillful operators. These errors may occur when taking CBCT, superimposing data files, or printing and milling surgical guides. Therefore, it is advisable to maintain a safety zone, keeping the implant approximately 2 mm away from vital structures, during the implant planning stage.

Furthermore, in this study, computer-assisted sur-

https://doi.org/10.4047/jap.2023.15.5.259

gical guides exhibited slightly higher standard deviations and larger ranges between the minimum deviations and maximum deviations, particularly in horizontal deviations at shoulder and angular deviations (Fig. 5 and Fig. 6). This variance may be attributed to imprecise seating and slight movements of the surgical guides during the serial drilling in some cases. In particular, anterior tooth-supported surgical guides are inherently more susceptible to displacement than their posterior counterparts, primarily due to the decreased support area according to their tooth morphology and inclination.[40] Hence, it would be prudent to emphasize the precise seating and immobilization of surgical guides during the entire drilling process, particularly in the anterior region.

In the case of the CSG, errors can also arise due to the polymerization shrinkage of the light-cured resin in the "Pre-guide" tray. However, this can be compensated by polymerizing the tray only after properly seating it in the patient's mouth and carefully following the manufacturer's instructions, as well as by adjusting the tray after polymerization to ensure a proper fit before CBCT.[25]

Overall, the accuracy of the novel CAD-CAM CSG (VARO Guide) was not significantly different from that of the 3D-printed surgical guide, regardless of the level of surgical experience. Moreover, the CAD-CAM CSG system facilitated the rapid fabrication of surgical guides in the dental office, allowing same-day computer-assisted implant surgery. Therefore, it may be considered a viable option to achieve successful implant surgery with satisfactory implant positioning, even by less experienced dentists, while optimizing patient convenience by minimizing appointment visits.

However, there are limitations to this study. First, although the real maxillary arch was simulated as closely as possible, the resin study models may not accurately represent the actual clinical environment. Second, in intraoral situations, factors such as patient movement, limited interocclusal distance, the presence of the lip, tongue, cheek, blood, and saliva, and stress level of the surgeons may affect the accuracy of the implant positions. For this reason, further clinical trials evaluating the accuracy of the CAD-CAM CSG compared to different types of surgical guides are necessary for a comprehensive clinical interpretation.

CONCLUSION

The CSG improves the clinical performance of dentists in implant placement in the maxillary anterior esthetic region, narrowing the accuracy gap between the different levels of surgical experience compared to the MSG. Moreover, the CSG showed comparable accuracy to the 3DSG in dental implant placement in the maxillary anterior esthetic region across different levels of surgical experience, while offering the advantage of shorter manufacturing time and reduced patient visits. However, more studies are necessary to address the limitations of *in vitro* studies by conducting more comprehensive clinical trials.

REFERENCES

1. Jung RE, Pjetursson BE, Glauser R, Zembic A, Zwahlen M, Lang NP. A systematic review of the 5-year survival and complication rates of implant-supported single crowns. Clin Oral Implants Res 2008;19:119-30.
2. French D, Ofec R, Levin L. Long term clinical performance of 10 871 dental implants with up to 22 years of follow-up: A cohort study in 4247 patients. Clin Implant Dent Relat Res 2021;23:289-97.
3. Kiatkroekkrai P, Takolpuckdee C, Subbalekha K, Mattheos N, Pimkhaokham A. Accuracy of implant position when placed using static computer-assisted implant surgical guides manufactured with two different optical scanning techniques: a randomized clinical trial. Int J Oral Maxillofac Surg 2020;49:377-83.
4. Buser D, Martin W, Belser UC. Optimizing esthetics for implant restorations in the anterior maxilla: anatomic and surgical considerations. Int J Oral Maxillofac Implants 2004;19 Suppl:43-61.
5. Grunder U, Gracis S, Capelli M. Influence of the 3-D bone-to-implant relationship on esthetics. Int J Periodontics Restorative Dent 2005;25:113-9.
6. Monje A, Insua A, Wang HL. Understanding peri-implantitis as a plaque-associated and site-specific entity: on the local predisposing factors. J Clin Med 2019;8:279.
7. Leesungbok R. Dr. Lee's Top-Down implant dentistry. Seoul; Myoungmoon Publishing; 2004. p. 8-24.
8. Garber DA, Belser UC. Restoration-driven implant placement with restoration-generated site develop-

ment. Compend Contin Educ Dent 1995;16:796, 798-802, 804.
9. Brugnami F, Caleffi C. Prosthetically driven implant placement. How to achieve the appropriate implant site development. Keio J Med 2005;54:172-8.
10. Ramasamy M, Giri, Raja R, Subramonian, Karthik, Narendrakumar R. Implant surgical guides: From the past to the present. J Pharm Bioallied Sci 2013;5(Suppl 1):S98-102.
11. 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.
12. Engelman MJ, Sorensen JA, Moy P. Optimum placement of osseointegrated implants. J Prosthet Dent 1988;59:467-73.
13. Balshi TJ, Garver DG. Surgical guidestents for placement of implants. J Oral Maxillofac Surg 1987;45:463-5.
14. Meitner SW, Tallents RH. Surgical templates for prosthetically guided implant placement. J Prosthet Dent 2004;92:569-74.
15. Vercruyssen M, Coucke W, Naert I, Jacobs R, Teughels W, Quirynen M. Depth and lateral deviations in guided implant surgery: an RCT comparing guided surgery with mental navigation or the use of a pilot-drill template. Clin Oral Implants Res 2015;26:1315-20.
16. Jung RE, Schneider D, Ganeles J, Wismeijer D, Zwahlen M, Hämmerle CH, Tahmaseb A. Computer technology applications in surgical implant dentistry: a systematic review. Int J Oral Maxillofac Implants 2009;24 Suppl:92-109.
17. Chackartchi T, Romanos GE, Parkanyi L, Schwarz F, Sculean A. Reducing errors in guided implant surgery to optimize treatment outcomes. Periodontol 2000 2022;88:64-72.
18. Joda T, Gallucci GO. The virtual patient in dental medicine. Clin Oral Implants Res 2015;26:725-6.
19. D'Souza KM, Aras MA. Types of implant surgical guides in dentistry: a review. J Oral Implantol 2012;38:643-52.
20. Fortin T, Champleboux G, Bianchi S, Buatois H, Coudert JL. Precision of transfer of preoperative planning for oral implants based on cone-beam CT-scan images through a robotic drilling machine. Clin Oral Implants Res 2002;13:651-6.
21. Park JM, Yi TK, Koak JY, Kim SK, Park EJ, Heo SJ. Comparison of five-axis milling and rapid prototyping for implant surgical templates. Int J Oral Maxillofac Implants 2014;29:374-83.
22. Hinckfuss S, Conrad HJ, Lin L, Lunos S, Seong WJ. Effect of surgical guide design and surgeon's experience on the accuracy of implant placement. J Oral Implantol 2012;38:311-23.
23. Park SJ, Leesungbok R, Cui T, Lee SW, Ahn SJ. Reliability of a CAD/CAM surgical guide for implant placement: an in vitro comparison of surgeons' experience levels and implant sites. Int J Prosthodont 2017;30:367-9.
24. Graf T, Keul C, Wismeijer D, Güth JF. Time and costs related to computer-assisted versus non-computer-assisted implant planning and surgery. A systematic review. Clin Oral Implants Res 2021;32 Suppl 21:303-17.
25. Hyun SW, Leesungbok R, Lee SW, Cho YE. Computer-guided implant surgery and immediate provisionalization by chair-side CAD-CAM: A case report. J Korean Acad Prosthodont 2021;59:478-86.
26. Song YW, Kim J, Kim JH, Park JM, Jung UW, Cha JK. Accuracy of dental implant placement by a novel in-house model-free and zero-setup fully guided surgical template made of a light-cured composite resin (VARO Guide®): a comparative in vitro study. Materials (Basel) 2021;14:4023.
27. Misch CE. Density of bone: effect on treatment plans, surgical approach, healing, and progressive boen loading. Int J Oral Implantol 1990;6:23-31.
28. Noharet R, Pettersson A, Bourgeois D. Accuracy of implant placement in the posterior maxilla as related to 2 types of surgical guides: a pilot study in the human cadaver. J Prosthet Dent 2014;112:526-32.
29. Vermeulen J. The accuracy of implant placement by experienced surgeons: guided vs freehand approach in a simulated plastic model. Int J Oral Maxillofac Implants 2017;32:617-24.
30. Chen Z, Li J, Sinjab K, Mendonca G, Yu H, Wang HL. Accuracy of flapless immediate implant placement in anterior maxilla using computer-assisted versus freehand surgery: A cadaver study. Clin Oral Implants Res 2018;29:1186-94.
31. Tahmaseb A, Wu V, Wismeijer D, Coucke W, Evans C. The accuracy of static computer-aided implant surgery: A systematic review and meta-analysis. Clin Oral Implants Res 2018;29 Suppl 16:416-35.

https://doi.org/10.4047/jap.2023.15.5.259

32. Abduo J, Lau D. Accuracy of static computer-assisted implant placement in anterior and posterior sites by clinicians new to implant dentistry: in vitro comparison of fully guided, pilot-guided, and freehand protocols. Int J Implant Dent 2020;6:10.
33. Schneider D, Sax C, Sancho-Puchades M, Hämmerle CHF, Jung RE. Accuracy of computer-assisted, template-guided implant placement compared with conventional implant placement by hand-An in vitro study. Clin Oral Implants Res 2021;32:1052-60.
34. Rungcharassaeng K, Caruso JM, Kan JY, Schutyser F, Boumans T. Accuracy of computer-guided surgery: a comparison of operator experience. J Prosthet Dent 2015;114:407-13.
35. Cushen SE, Turkyilmaz I. Impact of operator experience on the accuracy of implant placement with stereolithographic surgical templates: an in vitro study. J Prosthet Dent 2013;109:248-54.
36. Wang X, Shaheen E, Shujaat S, Meeus J, Legrand P, Lahoud P, do Nascimento Gerhardt M, Politis C, Jacobs R. Influence of experience on dental implant placement: an in vitro comparison of freehand, static guided and dynamic navigation approaches. Int J Implant Dent 2022;8:42.
37. Fürhauser R, Mailath-Pokorny G, Haas R, Busenlechner D, Watzek G, Pommer B. Esthetics of flapless single-tooth implants in the anterior maxilla using guided surgery: association of three-dimensional accuracy and pink esthetic score. Clin Implant Dent Relat Res 2015;17 Suppl 2:e427-33.
38. Singthong W, Serichetaphongse P, Chengprapakorn W. A randomized clinical trial on the accuracy of guided implant surgery between two implant-planning programs used by inexperienced operators. J Prosthet Dent 2022:S0022-3913(22)00104-4.
39. Verhamme LM, Meijer GJ, Boumans T, de Haan AF, Bergé SJ, Maal TJ. A clinically relevant accuracy study of computer-planned implant placement in the edentulous maxilla using mucosa-supported surgical templates. Clin Implant Dent Relat Res 2015;17:343-52.
40. El Kholy K, Lazarin R, Janner SFM, Faerber K, Buser R, Buser D. Influence of surgical guide support and implant site location on accuracy of static computer-assisted implant surgery. Clin Oral Implants Res 2019;30:1067-75.