Journal of Dental Sciences 19 (2024) 39–45

Available online at www.sciencedirect.com

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Original Article

Accuracy of three types of digital guides for crown lengthening surgery: An in vitro study

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Received 25 May 2023; Final revision received 9 June 2023
Available online 21 June 2023

KEYWORDS
Computer-assisted surgery;
Crown lengthening;
Dental esthetic;
Digital technology

Abstract *Background/purpose:* The guided protocols always yield a higher accuracy than freehand surgery. However, the accuracy of digital guides for crown lengthening surgery (CLS) is unknown. The purpose of this study was to evaluate the trueness of 3 types of digital guides for CLS.

Materials and methods: Twenty individually designed maxillary models were divided into 4 groups according to surgical guides: type I (T1), type II (T2), type III (T3), and free-hand. T1 comprised a planed gingival margin at the tissue level. T2 included both the planed gingival margin and alveolar crest at the tissue level. T3 consisted of a planed gingival margin at the tissue level and an alveolar crest at the bone level. CLS was performed under the indication of the guides. Trueness of the guides was evaluated through the deviation of the gingival zenith and alveolar crest height.

Results: The control group had higher vertical and horizontal distance deviations of gingival zenith compared to the 3 digital guide groups ($P < 0.001$). There were no significant differences among the 3 test groups in terms of gingival zenith deviations ($P > 0.05$). With regard to height deviation of alveolar crest, the control and T1 groups were higher than T2 group ($P < 0.001$), while T3 group had the lowest deviations among the 4 groups ($P < 0.001$).

Conclusion: The digital guides assisted CLS procedures are more accurate than free-hand method. The trueness of type III guide was better than type I and type II.

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https://doi.org/10.1016/j.jds.2023.06.007

Introduction

Smile esthetics play an important role with respect to the attractiveness, friendliness, trustworthiness, intelligence, and self-confidence of a person, as perceived by others.[1] Excessive gingival display, also called gummy smile, in the esthetic area of the anterior teeth is one of the common factors affecting smile esthetics.[2] The most common dental etiology is altered passive eruption (APE), which leaves the gingival margin in a more coronal location with short clinical crowns.[3]

Crown lengthening surgery (CLS) is one of the most common periodontal procedures, in which gingivectomy and alveolectomy are both typically involved for functional and esthetic purposes.[4–7] Gargiulo et al.[8] reported the average dimensions of the epithelial attachment as 0.97 mm, the connective tissue attachment as 1.07 mm, and the gingival sulcus as 0.69 mm. In contemporary practice, it is generally accepted that the distance from the alveolar crest to the free gingival margin is 3 mm (2 mm of biologic width plus mean 1 mm of sulcus depth).[9,10] With the increasing popularity of esthetically oriented therapy, CLS is widely used in the esthetic zone to correct gingival margin asymmetries, to enhance the appearance of restorations, and to expose the normal anatomical crowns.[11–13] Achieving and maintaining the ideal gingival margin level and structure constitute the basic requirements of esthetic CLS.[14]

The accuracy of the gingival margin after CLS is affected by several factors, mainly including the post-surgical flap position, amount of bone resection, periodontal biotype, surgical technique, and healing time.[10,12,15–17] A systematic review reported that the position of the gingival incision and the extent of the alveolectomy are the primary factors used to determine the gingival margin positional stability after CLS.[18] To obtain a predictable post-operative gingival position, surgical guides are used to improve the accuracy of CLS based on preoperative esthetic design and dentist-patient communications.

Traditional CLS guides are simple and inexpensive to generate, in that the guides typically include diagnostic wax, an acrylic resin, and a vacuum-formed surgical guide.[19–22] With the development of computer-aided design and computer-aided manufacturing (CAD-CAM) in dentistry, digital guides are increasingly being used in CLS.[23–25] Compared with traditional guides, digital guides offer significant advantages for providing more predictable surgical outcomes and shortening the clinical time.[25,26] Our group[27] has created a primary classification scheme for digital surgical guides for CLS, consisting of 3 types depending on the length indicator unit. Type I guides indicate a planed gingival margin only at the tissue level.[28] Type II guides comprise both the planed gingival margin and alveolar crest at the tissue level.[29,30] Type III guides consist of a planed gingival margin at the tissue level and an alveolar crest at the bone level, respectively.[31]

A systematic review reported that using digital guides is more predictable and time-saving than conventional guide surgery.[32] However, insufficient information was provided regarding the accuracy among the digital guides. Accuracy consists of trueness and precision. Trueness is determined as the difference between the actual and planned positions, while precision is defined by the consistency between multiple measurements.[33] The purpose of this in vitro study was to evaluate the trueness among 3 types of digital guides. The null hypothesis was that the digital guides have no effect on the accuracy of CLS procedures.

Materials and methods

This controlled study was performed according to the checklist for reporting in vitro studies (CRIS guidelines).[34] The overall process of the experiment is summarized as follows: preparing the individual models, designing the digital guides for the models, performing CLS under the guidance of the digital guides, and finally measuring the trueness of the guided surgery.

Model preparation

Individually designed maxillary models with APE were prepared from the radiopaque resin base, artificial resin teeth, and artificial gingiva (IDM, Hanru, Handan, China). The models had excessive keratinized tissue, with a short clinical crown length (Fig. 1A); the alveolar crest was extremely close to the crown (Fig. 1B).

Surgical guides design

The esthetic defects were analyzed to create a model of the 6 maxillary anterior teeth (bilateral central incisors to canines). The gingival margin was determined, based on a 0.8 width-to-length (W/L) ratio of maxillary anterior teeth.[35] The gingival zenith positions of the central incisors, lateral incisors, and canines were located at about

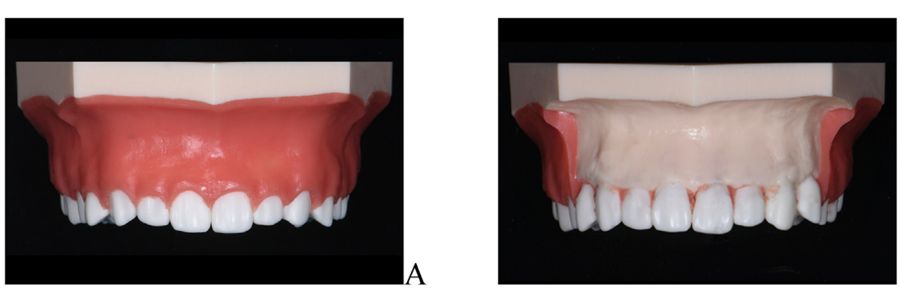

Figure 1 Individually designed maxillary models with altered passive eruption. A, Excessive keratinized tissue. B, Crown-oriented alveolar crest.

1, 0.5, and 0 mm distal from the long axis of the tooth, respectively,[36] while taking into account the bilateral gingival margin symmetry and coordination. Subsequently, CLS of the 6 anterior teeth was conducted using the constructed models.

A total of 20 models including 120 target anterior teeth were divided into 4 groups: type I guide group (T1G) (Fig. 2A1, A2), type II guide group (T2G) (Fig. 2B1, 2B2), type III guide group (T3G) (Fig. 2C1, C2), and the control group (CG). Six anterior tooth CLS guides were designed for each model. Each guide was made using CAD-CAM. The specific morphology of the 3 digital guide types (I—III) were shown in Fig. 2. Type I and II guides used one plate, and the type III guide included two plates that comprised a gingivectomy guide and an alveolectomy guide.

Surface scans of the 4 groups models were created with an intraoral scanner (TRIOS 3.0, 3Shape, Copenhagen, Denmark) to obtain standard tessellation language (STL) files A. These files were then exported to a digital dental software program (Dental DB 3.0 Galway, Exocad GmbH, Darmstadt, Germany). The program was then used to design a model of the gingival margin (T1G, T2G, and T3G) and the alveolar crest (T2G) at the tissue level (File A) to create the type I (Fig. 2A), II (Fig. 2B), and III gingivectomy guides (Fig. 2C1).

Make a cone beam computed tomography (NewTom, Cefla, Verona, Italy) scan to obtain the bone and teeth morphology of T3G. Image data were exported using the digital imaging and communications in medicine (DICOM) format to a virtual planning software program (Mimics Research 21.0 Beta, Materialise NV, Leuven, Belgium) to determine the bone tissue to be extracted; these files were consolidated as File B. Files A and B were imported into a digital dental software program (Dental DB 3.0 Galway, Exocad GmbH). A best-fit algorithm was used to merge the two files (saved as File C). The prospective alveolar crest was then drawn, at a distance of 3 mm from the prospective gingival margin at the bone level (Fig. 2C2). The type III guide design included an open window to expose the gingiva and alveolar bone to be removed (Fig. 2C1, C2).

After the design had been successfully completed, the CLS guide files were exported to a 3-dimensional printer (D20, Rapidshape GmbH, Heimsheim, Germany) to fabricate the digital guides. The printing material was high temp resin with 78% photosensitive resin, 21% sustained release agent and 1% other material. The support rods are placed on the lip surface for printing.

Crown lengthening surgery

CLS was performed on the 6 anterior teeth by the same clinician. For the CG, the operator used a periodontal probe to determine the gingival marginal position (Fig. 3A). For the test groups (T1G, T2G, and T3G), the gingival margin was determined according to the type I-III guides of gingivectomy (Fig. 3B—D). For all groups, an internal bevel incision was made with a 15C scalpel, and then carefully

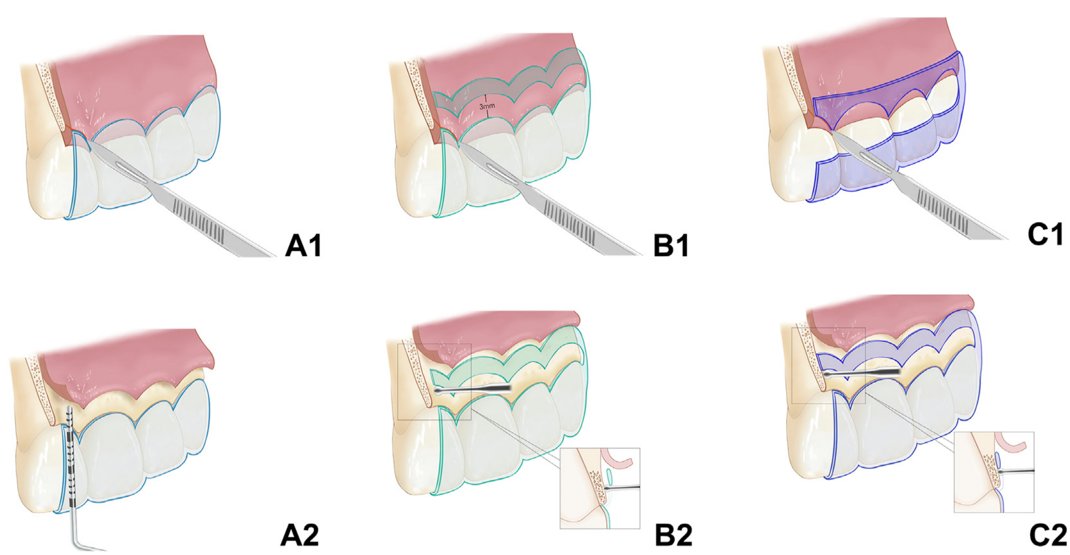

Figure 2 Length indicator unit (LIU) classification of surgical guides for crown lengthening surgery. A, Type I guide. B, Type II guide. C, Type III guide. 1, Indication for gingivectomy. 2, Indication for alveolectomy.

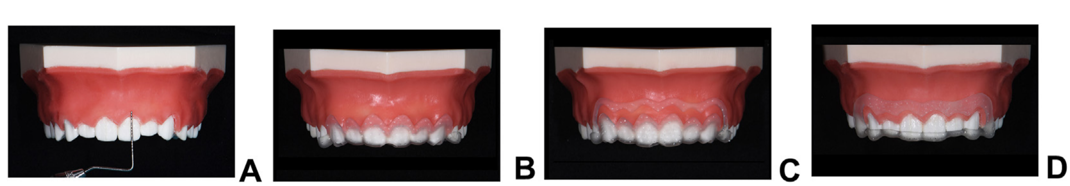

Figure 3 Indication of gingivectomy of crown lengthening surgery. A, Control group. B, Type I guide group. C, Type II guide group. D, Type III guide group of gingivectomy.

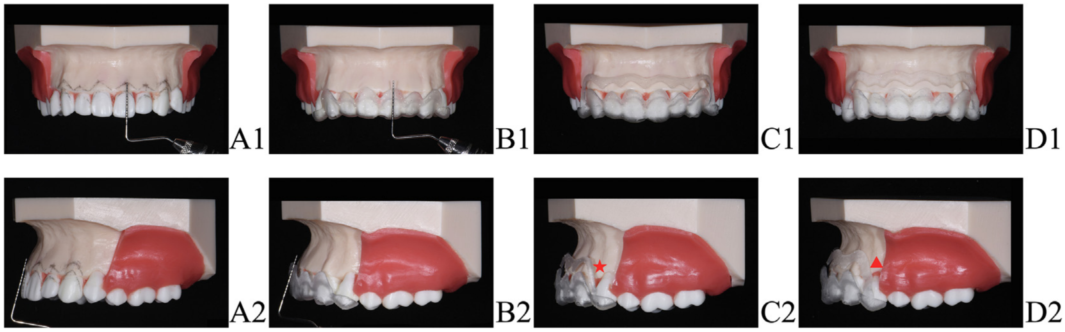

Figure 4 Indication of alveolectomy of crown lengthening surgery. A, Control group. B, Type I guide group. C, Type II guide group. D, Type III guide group of alveolectomy. 1, Front view. 2, Lateral view. ★, Guide was remote from bone. ▲, Guide adhered to bone.

removed the collar tissue. Intraoral surface scans of the models were performed after the gingivectomy, using an intraoral scanner (TRIOS 3.0, 3Shape) to record the gingival margin position.

The gingiva was elevated to expose the alveolar bone. For CG, the surgeon used a periodontal probe to determine the alveolar crest position based on the margin of the incisor (Fig. 4A1, A2). For T1G, the surgeon used a periodontal probe to determine the alveolar crest position based on the gingival margin of the type I guide (Fig. 4B1, B2). For T2G and T3G, digital guides were used to determine the position of the alveolar crest and to remove the excess bone through the windows in the alveolectomy guide. The type II digital guide in T2G was designed at the tissue level, the guide was remote from the bone level after flap elevation (Fig. 4C1, C2). The type III digital guide in T3G was designed at the bone level, such that the guide adhered to the bone and limit bone resection (Fig. 4D1, D2). For all groups, a 1-mm tungsten carbide bur (FG2, Dentsply, Charlotte, NC, USA) was used for bone resection. After the alveolectomy, surface scans of the models were created with an intraoral scanner (TRIOS 3.0, 3Shape) to record the alveolar crest position after surgery.

Evaluation standard

The trueness of the models was evaluated using the deviation in the vertical and horizontal positions of the gingival zenith and that in the height of the alveolar crest (Fig. 5) by spatial ruler measurement tool in digital dental software program (Dental DB 3.0 Galway, Exocad GmbH). The vertical position of the gingival zenith was calculated as the distance from the incisor to the gingival zenith position. The horizontal position of the gingival zenith was measured as the vertical distance from the gingival zenith position to the long axis of the tooth. We compared the deviation in the zenith position of the models between the virtual planning position and the actual position attained after surgery. The alveolar crest height was calculated as the distance from the incisor to the alveolar crest. We then compared the difference between the designed value and the postoperative value.

Statistical analysis

The mean and standard deviation were calculated using a statistical analysis software program (IBM-SPSS Statistics v27.0, IBM Corp, Somers, NY, USA). Differences among the groups were analyzed using a 1-way analysis of variance and least significant difference post-hoc test ($\alpha = 0.05$).

Results

The mean vertical distance deviations between the virtually planned and actual positions of the gingival zenith are shown in Table 1. The deviations of the 3 digital guide groups were lower than that of the control group, and the difference was statistically significant ($P < 0.001$). There was no statistically significant difference ($P > 0.05$) in the deviation among the 3 digital guides (Fig. 6A).

The mean horizontal distance deviations of the gingival zenith are shown in Table 2. There was no statistically significant difference ($P > 0.05$) in the deviation among the 3 digital guide groups. The mean deviation of the CG was significantly higher than that of the 3 guide groups, and the difference was statistically significant ($P < 0.001$) (Fig. 6B).

The mean deviations of alveolar crest height are shown in Table 3. There was a statistically significant difference ($P < 0.001$) in the deviation among the 4 groups. The

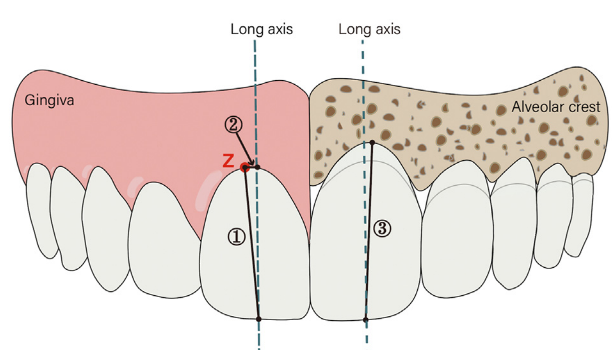

Figure 5 Assessed parameters of deviations from gingival zenith and alveolar crest positions. Z, Gingival zenith; ①, Vertical position of gingival zenith; ②, Horizontal position of gingival zenith; ③, Alveolar crest height.

Table 1 Vertical distance deviation (mm) of gingival zenith of 3 digital guides assisted crown lengthening surgery.

Groups	N	Mean	Standard deviation	Minimum	Maximum	P
CG	30	0.408[a]	0.176	0.105	0.848	
T1G	30	0.153[b]	0.110	0.003	0.375	<0.001
T2G	30	0.168[b]	0.124	0.004	0.430	
T3G	30	0.183[b]	0.112	0.019	0.376	

CG, control group; T1G, type I guide group; T2G, type II guide group; T3G, type III guide group. Different superscript letters (a, b) indicate statistically significant differences ($P < 0.05$).

control group showed no statistically significant difference with T1G ($P > 0.05$), but was significantly higher deviated than that with respect to T2G and T3G ($P < 0.001$). While T3 group had the lowest deviations among the 4 groups ($P < 0.001$) (Fig. 6C).

Discussion

The purpose of this controlled in vitro study was to evaluate the trueness among 3 types of digital guides. Compared with a free-hand approach, the use of a digital guide significantly improves the surgical accuracy. Therefore, the null hypothesis was rejected.

According to the esthetic parameters of maxillary anterior teeth area, the esthetic design of anterior teeth should comprehensively consider the position of the gingival margin and gingival zenith position.[36,37] The position of gingival margin and gingival zenith are determined through the guide design, so as to ensure the accuracy and to achieve the esthetic effect. For the gingivectomy, the trueness of using the digital guides was higher than that of the free-handed guide ($P < 0.001$); there was no significant difference ($P > 0.05$) among the 3 guides. The accuracy of the periodontal probe, and thus the surgical outcome, is limited by the operator's experience.[38] With computer-aided measurement and design, the digital guide can accurately indicate the incision position, which is more accurate than a periodontal probe measurement. Compared with the type I and II guides, the type III gingivectomy guide is located at the root direction of the incision, it can better protect the gingiva and prevents accidental injury; however, the influence of the incision angle should be considered in the design. Meanwhile, the 3 digital guides are closely attached to the gingival surface to guide gingival resection. Under the premise of accurate design details, there was no significant difference in accuracy ($P > 0.05$) among the 3 digital guides.

At the same time, the stability of the gingival margin was affected by the alveolar crest position.[9] For the alveolectomy, type II and type III guides can indicate alveolar resection more accurately than free-hand and type I guides ($P < 0.001$). Both the type I guide and the free-hand guide were used along with a periodontal probe; thus, the difference between them was not statistically significant ($P > 0.05$), and the overall precision was lower. The type II guide can indicate the position of the alveolar crest at the tissue level. The alveolectomy guide is remote from the bone level after flap elevation and is unable to constrain the bone resection; thus, improvement in the accuracy of the procedure is limited. The design of type III guide integrates CBCT and intraoral scanning data, so it can indicate the alveolar crest at the bone level; meanwhile, bone resection is constrained and the bone is better protected. As such, the type III guide provided the highest accuracy and was significantly better than the type II guide ($P < 0.001$).

Most of the previous literature focused on type I and type II guides, which only indicated surgery at the gingival level.[25,28–30] Due to the position of type I and II guides, it does not protect the gingiva and prevent accidental injury during gingivectomy. Meanwhile, the design of type I and II guides only based on oral scan data, so the guidance for alveolectomy is not effective. Therefore, we have improved the current guides. The type III guide is an innovative patented technology of our group, which integrates CBCT data to further indicate surgery at the bone level and improve the accuracy of surgery. Type III guides have a double length indicator unit that indicates the planed gingival margin at the tissue level and the alveolar crest at the bone level. The references at their respective levels avoid parallaxes and subsequent inaccuracy, thus enhancing treatment predictability.[31] In addition, the

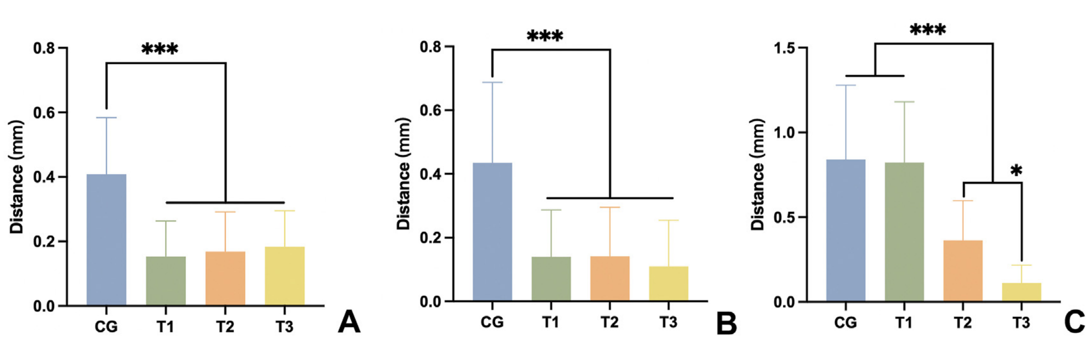

Figure 6 Distance deviation of crown lengthening surgery of 3 guide groups. A, Vertical distance deviation of gingival zenith. B, Horizontal distance deviation of gingival zenith. C, Height deviation of alveolar crest. CG, control group; T1G, type I guide group; T2G, type II guide group; T3G, type III guide group. ***Values show a statistically significant difference ($P < 0.001$). *Values show a statistically significant difference ($P < 0.05$).

Table 2 Horizontal distance deviation (mm) of gingival zenith of 3 digital guides assisted crown lengthening surgery.

Groups	N	Mean	Standard deviation	Minimum	Maximum	P
CG	30	0.435[a]	0.252	0.009	1.132	<0.001
T1G	30	0.140[b]	0.147	0.002	0.577	
T2G	30	0.142[b]	0.154	0.002	0.653	
T3G	30	0.116[b]	0.145	0.000	0.600	

CG, control group; T1G, type I guide group; T2G, type II guide group; T3G, type III guide group. Different superscript letters (a, b) indicate statistically significant differences ($P < 0.05$).

Table 3 Height deviation (mm) of alveolar crest of 3 digital guides assisted crown lengthening surgery.

Groups	N	Mean	Standard Deviation	Minimum	Maximum	P
CG	30	0.839[a]	0.439	0.086	1.810	<0.001
T1	30	0.823[a]	0.357	0.104	1.569	
T2	30	0.364[b]	0.234	0.096	0.889	
T3	30	0.112[c]	0.106	0.003	0.361	

CG, control group; T1G, type I guide group; T2G, type II guide group; T3G, type III guide group. Different superscript letters (a, b, c) indicate statistically significant differences ($P < 0.05$).

excess bone is removed through a window in the alveolectomy guide that is placed during the surgery, so as not to damage any reserved bone.

Although the use of a guide can improve surgical precision, the process of computer-aided design is complicated, time-consuming, and requires extensive software and hardware resources. In the future, a more simplified and efficient process should help to reduce costs for applications in clinical settings.

This study had several limitations. The guides can only indicate the position; gingivoplasty and osteoplasty procedures may still require surgical operator's experience. Meanwhile, an inexperienced surgeon is always dependent on the guide, while an experienced surgeon is able to adjust the surgical strategies according to the intraoperative situation. The accuracy of the gingival margin after CLS *in vivo* is also affected by the post-surgical flap position, amount of bone resection, periodontal biotype, surgical technique, and healing time. Thus, studies on the effects of the 3 digital guides on accuracy in clinical trials are necessary.

Based on the findings of this in vitro study, the following conclusions were drawn. With the help of digital guides, the CLS procedure was more accurate than a free-hand approach. For the gingivectomy procedure, the accuracy of the 3 digital guides (types I—III) showed no statistically significant differences among themselves, and all showed better accuracy than the control. For the alveolectomy procedure, the accuracy of the 3 digital guides showed statistically significant differences. The accuracy of the type III guide was superior to that of the type II guide, both of which were superior to the type I guide and control.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

This study was supported by Clinical Research Foundation of Peking University School and Hospital of Stomatology (PKUSS-2023CRF204) and Industry-University-Research Innovation Fund for Chinese Universities (2022BC001), China.

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