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CLINICAL RESEARCH

Accuracy of computer-guided implant placement in anterior regions

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ABSTRACT

Statement of problem. Implant placement in the anterior regions is often challenging because of limited space and bone volume availability.

Purpose. The purpose of this clinical study was to investigate the accuracy of computer-guided surgery with a long drill key to place implants in the anterior regions.

Material and methods. Computer-guided implant surgery was performed for 32 participants requiring implants in anterior regions. The procedure involved using a 12-mm-long drill key to guide the 2.0-mm-diameter drill. Deviations between the planned and actual implant positions were evaluated by using cone beam computed tomography (CBCT) scans obtained before and after surgery. A *t* test was used for comparisons between the planned and placed implants and to determine the influence of the arch (maxilla/mandible) and time (immediate/delayed) on accuracy.

Results. A total of 40 implants (20 implants in the maxilla and 20 implants in the mandible) were placed. The mean linear deviation was 0.46 mm (range, 0 to 1.15 mm) for the implant shoulder and 0.67 mm (range, 0.14 to 1.19 mm) for the implant apex. The mean angular deviation was 1.40 degrees (range, 0.30 to 2.57 degrees). The mean depth deviation was 0.15 mm (range, 0.10 to 0.82 mm).

Conclusions. This clinical study showed that the accuracy of computer-guided implant placement may be enhanced by using a long drill key and may thus enable more accurate implant placement in anterior regions. (J Prosthet Dent 2019;121:836-42)

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.[1] The implant position, especially in anterior regions, affects restoration esthetics.[2] However, implant placement in anterior regions is often challenging because of the limited space available between adjacent teeth.[3] Moreover, the available labiolingual bone is often unfavorable for implant placement.[3]

Computer-guided implant surgery is defined as the use of a surgical template that reproduces a virtual implant position designed from digital data.[4-7] However, previous studies concerning computer-guided implant placement have shown a mean inaccuracy at the implant entry point of 1.12 mm with a maximum of 4.5 mm and a mean inaccuracy at the implant apex of 1.39 mm with a maximum of 7.1 mm,[8-11] implying a lack of patient safety with this form of guidance system. The most important source of deviation resulted from the intrinsic error that originated from the mechanical component tolerance in the surgical templates.[12] In an in vitro study, lateral movements of the instrument tip of up to 2.7 mm were recorded if the drills were actively moved within their guides.[13,14] To reduce the tolerance between mechanical components, Schneider et al[14] used a longer drill key and reported that a longer drill key led to a longer guidance of the drill, thus reducing the lateral movement of the drill. The purpose of the present study was to investigate the accuracy of a computer-guided surgery system using a long drill key in participants requiring anterior implants.

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Clinical Implications

By using a long drill key, a computer-guided surgery system can increase the accuracy of implant placement and help dentists with precise implant placement in anterior regions.

The null hypotheses were that no deviations would be found between the planned and placed implant position with a computer-guided surgery system by using a long drill key; that no statistically significant deviations would be found in any direction between maxillary and mandibular implants inserted; and that no statistically significant deviations would be found in any direction between immediate and delayed implant placement.

MATERIAL AND METHODS

Thirty-two participants (mean age: 56 years; 18 women and 14 men) requiring implants in the anterior region were consecutively recruited. Their remaining dentition had a healthy periodontium without excessive tooth mobility. Implants were placed immediately after extraction (n=19) or into extraction sockets that had been healed for at least 3 months (n=21). In participants with immediate implant placement, bone grafting was performed as required after implant placement into the bone defects surrounding the implant surface. Sites with any disorders to the planned implant area, such as previous tumors, radiation, or bone diseases, were excluded.

The study was conducted at 4 sites (University Hospital of the Wonju College of Medicine, Yonsei University, Wonju, Korea; Segyero Dental Hospital, Pusan, Korea; Michigan Dental Clinic, Pusan, Korea; and the Welcome Dental Clinic, Pusan, Korea). Each site recruited 8 participants for a total of 32 participants in need of an implant-supported crown in an anterior region. Eight participants per center were chosen because of the difficulty in recruiting individuals who required implants in the anterior region and were concomitantly available for computed tomography studies. The clinical protocol was approved by the respective local ethical committees. Signed consent from each participant was obtained.

Cone beam computed tomography (CBCT) data of the maxillary and mandibular jaws were acquired using a dental computed tomography scanner (Point 3D Combi 500C; PointNix) for implant planning. Digital scans of the maxillary and mandibular teeth were made using an intraoral scanner (TRIOS 3; 3Shape A/S). Digital standard tessellation language (STL) files generated from the intraoral scan model were then imported into a virtual implant planning software program (Implant Studio; 3Shape A/S). The data acquired from the CBCT scan were also imported into the virtual implant planning software and then merged with the STL files.

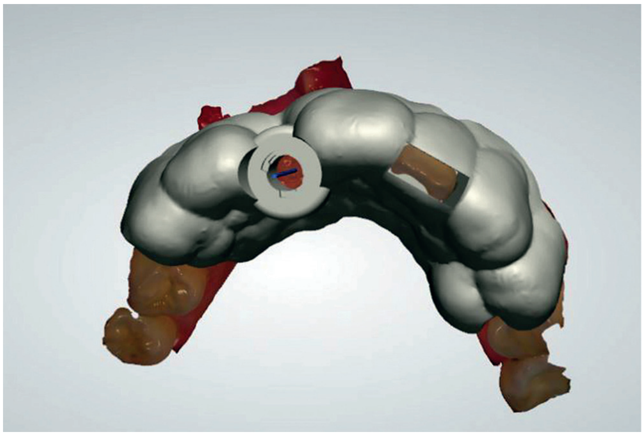

Figure 1. Design of surgical template.

After image fusion of the intraoral scan data and CBCT data, a prosthetically driven implant plan was conducted by using the virtual implant planning software. When implant planning was complete, a surgical template was designed with the same software and printed by using a commercial printable resin (DIOnavi-SG; DIO Inc) in a 3D printer (Probe; DIO Inc) (Fig. 1). For immediate restoration after implant placement, abutments and crowns were designed with a virtual design program (Dental Designer; 3Shape A/S) and fabricated by using a computer-assisted design and computer-assisted manufacturing (CAD-CAM) machine (Arum; Doowon). The abutments were milled in titanium, and cement-retained interim crowns were milled from polymethyl methacrylate (PMMA) blocks (Vipiblock; Shine Dental).

Computer-guided flapless implant surgery was performed under local anesthesia. First, the surgical template was placed in the patient's mouth, and then the template was evaluated for intraoral fit and stability (Fig. 2A). The tissue punch was the first drill used in the sequence (Fig. 2B). After punching the soft tissue, a bone-flattening drill was used to shave the crestal bone surface as flat as possible to guide the first osteotomy drill in the correct direction (Fig. 2C). After flattening the bone surface, an implant osteotomy was prepared using a 2.0-mm-diameter drill (Fig. 2D). Drilling with the 2.0-mm-diameter drill was guided using a 12-mm-long drill key (DIO Navi Guide; DIO Inc) (Fig. 3). The lower part of the drill key was designed to be inserted into the mucosa that had been removed after use of the tissue punch and the bone-flattening drill. Drilling was then performed by using sequential drills with increasing diameters through the guide, without using a drill key (Fig. 2E). Based on the results of previous studies,[15-17] all drillings were performed at a low speed (50 rpm) without irrigation.

Implants (UFII; DIO Inc) were placed with guidance provided from the surgical template (Fig. 2F). After implant placement, prefabricated abutments and cement-retained interim crowns were installed. The

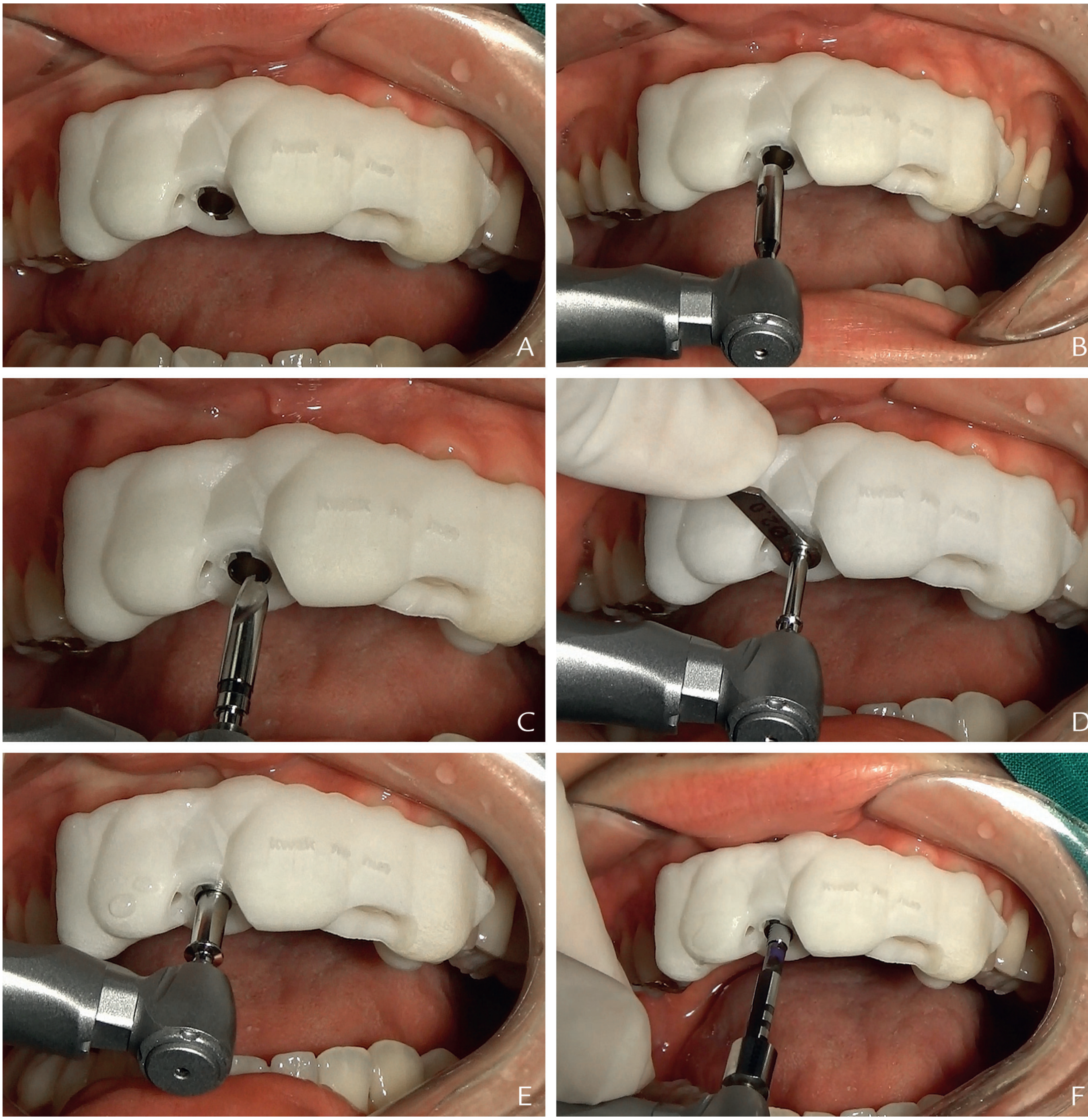

Figure 2. Implant placement procedure with surgical template. A, Surgical template in place. B, Tissue punch. C, Bone-flattening drill. D, 2.0-mm-diameter drill with 12-mm-long drill key. E, Sequential drill without drill key. F, Implant placement.

restoration process followed the immediate nonfunctional loading concept by adjusting the crown to avoid contact with the opposing teeth.

All participants underwent postoperative CBCT scanning. To calculate the deviations between the planned and the placed implants, objects in the preoperative images were overlapped with their counterparts in the postoperative images. Overlapping of the images was performed automatically using a software program (Mimics 21.0; Materialise Dental). The software ran until the exact overlap between the images of the preoperative and postoperative objects was identified and did not require intervention from the operator, therefore excluding bias (Fig. 4).[18] Four deviation parameters were calculated between the planned and the placed implants (Fig. 5): linear deviation at the implant shoulder; linear deviation at the implant apex; angular deviation; and depth deviation.

The data were analyzed with statistical software (IBM SPSS Statistics, v22; IBM Corp). A *t* test was used for

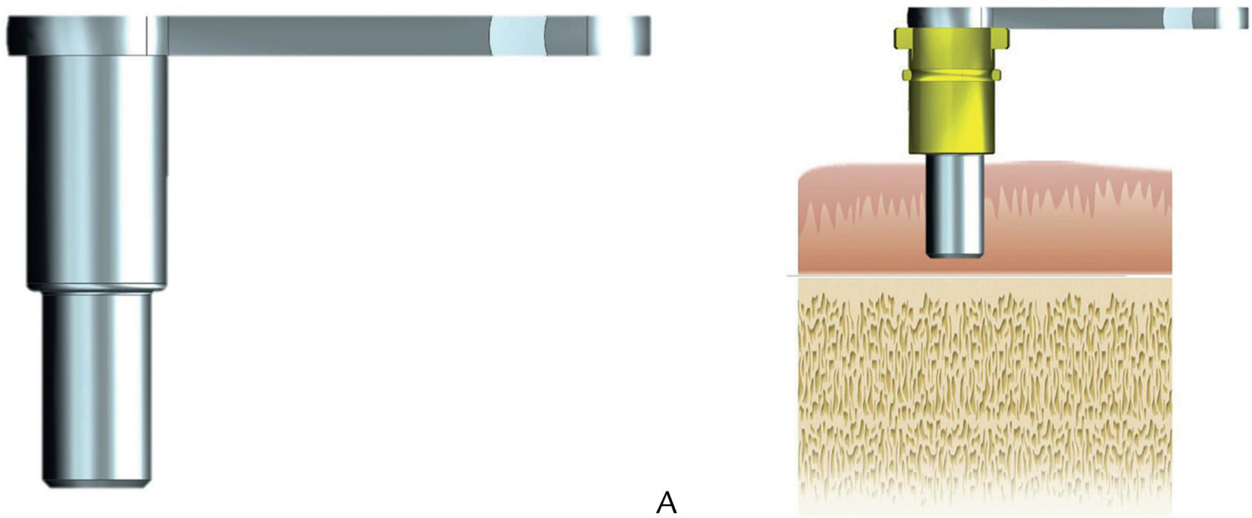

Figure 3. A, Long drill key. B, Lower part of drill key inserted into mucosa.

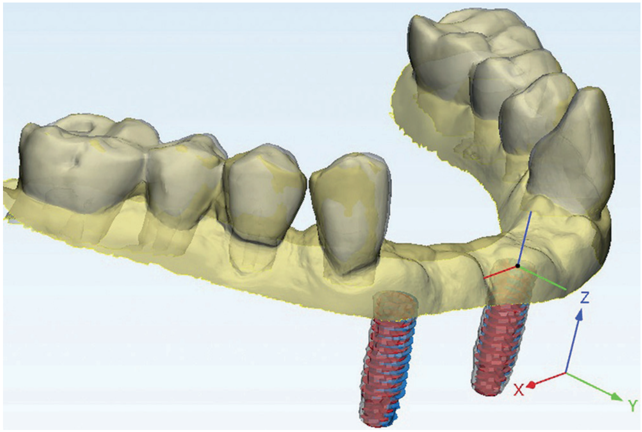

Figure 4. Preoperative and postoperative images overlapped automatically with Mimics software.

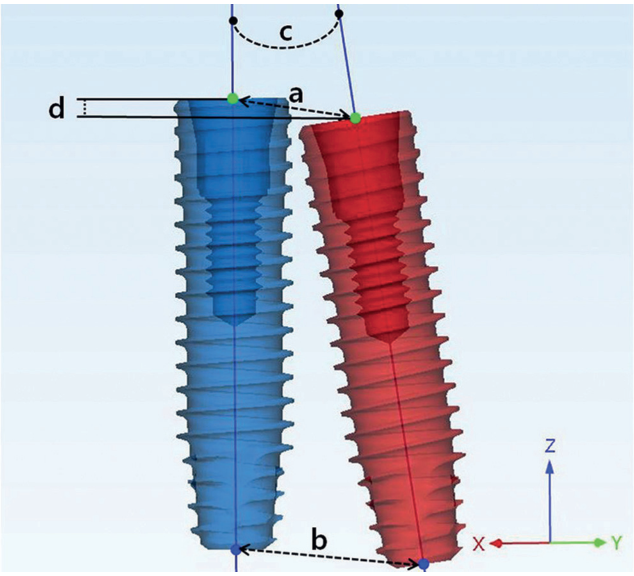

Figure 5. Four deviation parameters calculated between planned and placed implants: (a) deviation at implant platform; (b) deviation at implant apex; (c) angular deviation; and (d) depth deviation.

comparisons between the planned and placed implants in terms of angular deviations, deviations in position at the platform, and apex and depth deviations. The deviation data were described through division of the specimen into the following 2 groups: maxilla versus mandible and immediate versus delayed implant placement. A Student *t* test was used to determine the influence of the arch (maxilla or mandible) and time (immediate or delayed) on accuracy (α=.05).

RESULTS

A total of 40 implants were inserted. Immediate implant placement after extraction was performed in 19 participants; delayed implant placement occurred in 21 participants. Twenty implants were inserted in the mandibular anterior region and 20 in the maxillary anterior region. All implants were accurately placed relative to the preoperative plan (Fig. 6). All implants were immediately restored with interim crowns that were fabricated before the surgery. The implants inserted were 3.0 mm or 3.3 mm in diameter and 10 to 13 mm in length.

The mean linear deviation was 0.46 mm (range, 0 to 1.15 mm) for the implant shoulder and 0.67 mm (range, 0.14 to 1.19 mm) for the implant apex. The mean angular deviation was 1.40 degrees (range, 0.30 to 2.57 degrees). The mean depth deviation was 0.15 mm (range, 0.10 to 0.82 mm). The differences between virtually planned implants and actual positions of the implants were statistically significant for all variables (P<.05). Regarding the influence of the arch (maxilla or mandible) on

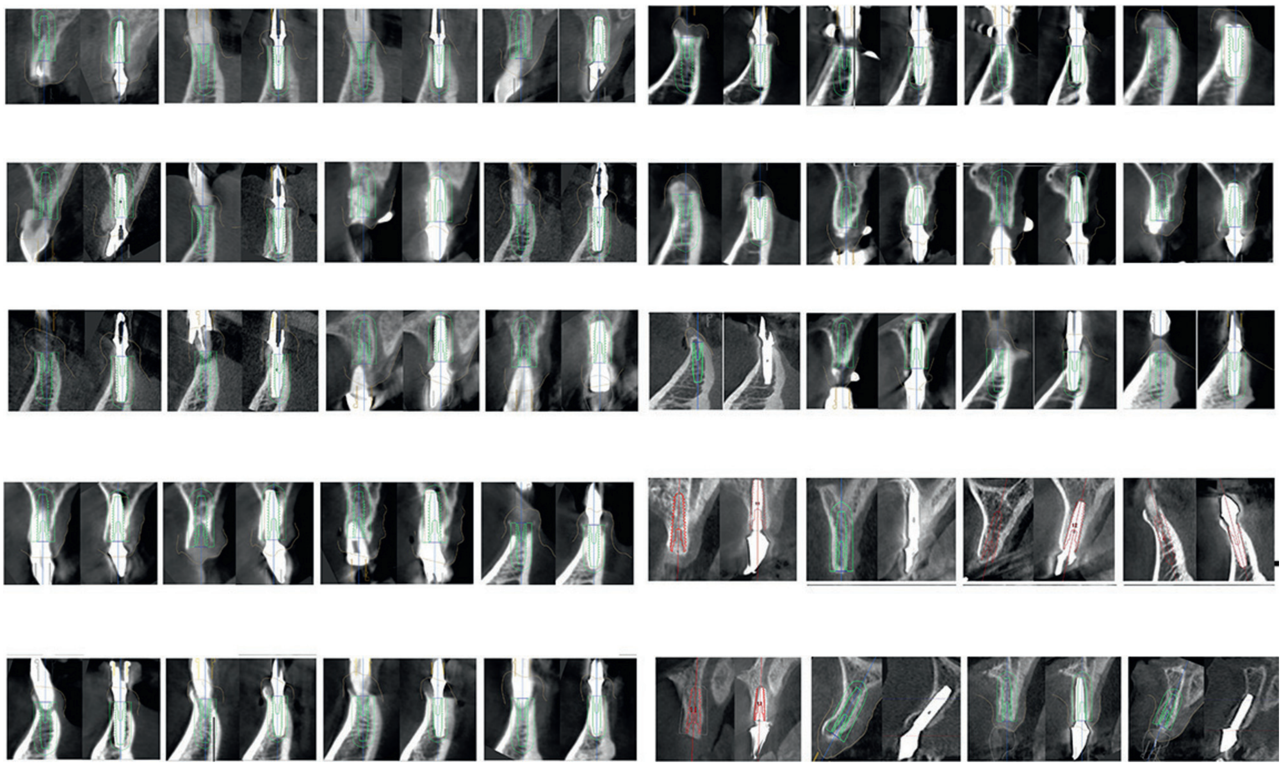

Figure 6. Cone beam computed tomography (CBCT) scans obtained before and after surgery from 32 participants.

accuracy, the *t* test showed no significant difference between the 2 groups (*P*=.319). Regarding the influence of time (immediate or delayed) on accuracy, no significant differences were found between the 2 groups (*P*=.232).

DISCUSSION

The first null hypothesis that no deviations would be found between the planned and placed implant position with a computer-guided surgery system by using a long drill key was rejected. The results demonstrated a significant difference between virtually planned implants and actually placed implants in terms of angular deviations, deviations in position at the platform, and apex and depth deviations. However, although the values were statistically significant, the computer-guided system used in the present study allowed higher accuracy of implant placement than that previously reported.[8-11]

Cristache and Gurbanescu[8] reported that from 65 consecutive implants inserted with the direct drill-guiding system, the placement errors measured were 0.79 (maximum, 2.30 mm) at the entry point and 1.17 (maximum, 3.22 mm) at the apex; mean angular deviation was 2.34 (maximum, 4.22 degrees). Tahmaseb et al,[9] in a systematic review of data retrieved from 24 studies, reported an inaccuracy at the implant entry point of 1.12 mm with a maximum of 4.5 mm on 1530 implants and an inaccuracy of 1.39 mm at the apex of implants with a maximum of 7.1 mm when measured on 1465 implants. Shen et al[10] reported that from 57 implants inserted with the assistance of surgical templates, variation was 1.18 ±0.72 mm at the implant platform, 1.43 ±0.74 mm at the apex, 4.21 ±1.91 degrees in angulation, and 0.54 ±0.29 mm in depth. Schneider et al,[11] in a systematic review of the accuracy of computer-guided systems, reported that the mean horizontal deviation was approximately 1 mm at the entry point, approximately 1.6 mm at the apex, 0.5 mm in height, and 5 to 6 degrees in axis. In the present study, mean angular deviation was 1.40 degrees with a maximum of 2.57 degrees and mean linear deviation was 0.67 mm with a maximum of 1.19 mm for the implant apex and 0.46 mm with a maximum of 1.15 mm for the implant platform.

The higher accuracy in implant placement may be from the long drill key that guided the first osteotomy drill (a 2.0-mm-diameter drill) inside the surgical templates. The first drill is the most important because it determines the drilling axis. If an error occurs in the drilling axis inside the bone, it is difficult to correct or adjust the error. Therefore, the drill conditions for the first drill should be optimized to reduce deviation of the implant placement. In the present study, a long drill channel was created by using a 12-mm-long drill key that led to a long guidance for the first drill within the surgical template, thereby reducing the lateral movement of the drill. These findings are consistent with those reported by

Choi et al,[19] who evaluated the effects of surgical guide channel length on implant placement error in an in vitro investigation. They found that the channel length was the primary controlling factor in minimizing deviated implant angulations and recommended the use of the longest channel possible to reduce the deviation.[19] These findings are in contrast with the findings of Park et al,[1] who compared the influence of 4-, 6-, and 8-mm guide heights on the accuracy of implant placement and reported that the guide height did not affect the accuracy of the implant position. The inconsistency between these results may be because Park et al[1] used a single drill key of 5 mm in height and did not use incremental drill keys.

Maximizing surgical space and maintaining the accuracy of implant placement are key factors for surgical templates, as they may interfere with the effective use of surgical instruments.[20] In this study, interference between the surgical handpiece and the opposing arch did not occur when drilling was performed with the long drill key. This may have been because the drill channel was improved without increasing the distance between the prospective implant shoulder and the top of the surgical template and because the lower part of the drill key was inserted into the mucosa that was removed after using a tissue punch and a bone-flattening drill.

The second hypothesis that no statistically significant deviations would be found in any direction between the maxillary and mandibular implants inserted was not rejected. The results demonstrated no significant difference between the results of the mandible and maxilla for angular deviations, deviations in position at the platform, and apex and depth deviations. An explanation for this observation could be that the use of longer guide keys was facilitated by implant location in anterior regions. Schneider et al[11] reported that the maximum inaccuracy registered was measured for implants inserted in the posterior maxilla; limited access with surgical instruments in the posterior area caused high implant placement error. In the present study, as all implants were placed in anterior region, surgery with a surgical template was not compromised by the site of implant placement, either in the mandible or maxilla.

We hypothesized that no statistically significant deviations would be found in any direction between immediate and delayed implant placement. The results of this study did not support rejection of this third hypothesis regarding inaccuracy between immediate and delayed implants. An explanation for this observation could be that the use of bone-flattening drills creates a platform for drilling with the first osteotomy drill by leveling the alveolar bone. The main difference between immediate and delayed implants is that in the immediate implants, extraction sockets are not filled with bone. In the present study, the bone-flattening drill could flatten both crestal bone and socket surfaces to guide the first osteotomy drill in the correct direction, thus preventing the drill from slipping on the bone surface.

The most notable error with guided surgery occurs in the vertical direction (an overly superficial implant position) due to the blockage of the implant holders in the sleeves of the template during surgery.[21] Blockage is a secondary phenomenon resulting from deviation when drilling. In the present study, blockage did not occur as the use of the long drill key optimized the drilling procedure. The mean vertical discrepancy was 0.15 mm. This appears to have been a better result in comparison with other studies.[22-25] The high accuracy in the vertical direction may be due to minimal error from the intraoral digital scans, image fusion, fixation of the surgical guide, and drilling of the osteotomy. In addition, the depth control system indicating the stop point, such as a stopper and a reference line, was useful for placing the implant at the planned depth.

One limitation of the present study is that radiation exposure from the before and after CBCT scans was required to evaluate the precision of planned and placed implants. In future studies, if implant placement accuracy is assessed by matching the preoperative treatment plan imaging with postoperative digital scanning imaging, without the requirement for postoperative CBCT, further radiation exposure may be avoided. Another limitation is that the findings were derived from a small number of implant placements. Hence, further studies with larger numbers of participants may be necessary to determine whether these trends continue and how accurate the long key technique is compared with a conventional control group.

CONCLUSIONS

Based on the findings of this clinical study, the following conclusion was drawn:

1. The accuracy of computer-guided implant placement may be enhanced by using a long drill key and may thus enable more accurate implant placement in anterior regions.

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