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Accuracy and Wear Evaluation of the Customized Zirconia Guided Sleeves

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Abstract: This in vitro study investigated the accuracy and wear conditions of three drill sleeve distances (0.01, 0.02, and 0.03 mm) for 3D-guided stents in simulated clinical dental implant surgery. Fifteen sets of upper and lower partially edentulous epoxy tooling board models with four edentulous first molar sites were prepared in a Nissin Simple Manikin II and set on a dental chair. Sixty computer-aided design and computer-aided manufacturing (CAD/CAM) designed and guided stents with three drill sleeve distances were prepared in this study. The maximum height (Sz) of the wear roughness of drills, maximum deviation, and drilling time were observed. The highest maximum horizontal deviations were observed at the upper first molar (0.48 ± 0.12 mm, $p < 0.001$). The highest maximum vertical and angular deviations were observed at the lower left first molar (1.08 ± 0.35 mm and 5.61° ± 1.21°, respectively, $p < 0.001$). Only angular deviation significantly differed among the three drill sleeve distances ($p = 0.046$); the 0.03 mm distance exhibited the maximum angular deviation (3.92° ± 1.87°). The bigger drill sleeve distance (0.03 mm) was associated with more wear roughness (8.70 ± 2.29 µm) of the drills. Guided stents with varying drill-sleeve distances (0.01, 0.02, and 0.03 mm) exhibited no significant difference in preparation drilling time and abrasive wear. In practice, the optimal drill sleeve distance for single-type CAD/CAM-guided stents of dental implantation was 0.01 mm.

Keywords: drill sleeve distance; dental implant; CAD/CAM; guided stent

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1. Introduction

Modern advancements in implant dentistry have revolutionized computer-assisted digital workflows [1]. Computer-guided implant surgery has been demonstrated to be more precise and accurate than conventional surgical guides or free-hand implant placement [2–8]. Cone-beam computed tomography (CBCT) produces 3-dimensional (3D) images that can be stored as digital imaging and communications in medicine (DICOM) files, and intraoral scan and conventional models can generate images as stereolithography (STL) files. Software can merge DICOM and STL files, virtual planning software can be used to determine the ideal implant position for the surgical guided stent. These guides are produced using CAD/CAM technology (e.g., stereolithography models) or manually produced in a dental laboratory using computer-aided implantology (CAI) [9–11].

Tang et al. [7] demonstrated that an implant deviation of 1.22 ± 0.63 mm at the entrance point and 1.91 ± 1.17 mm at the apical point and an angulation of 7.93° ± 5.56° were achieved through free-hand placement. The application of a CAI surgical template during surgery could enhance the accuracy of implant placement. Yeung et al. [12] examined implant installation by using 3D-printed guides and reported a deviation of 0.02 ± 0.13 mm mesially and 0.07 ± 0.14 mm distally and a mesiodistal angulation of 1.69° ± 1.02° and a labiopalatal angulation of 1.56° ± 0.92°. However, in their systematic review, Tahmaseb et al. [8] reported that the mean errors of implant placement were approximately 1.2 and 1.4 mm at the coronal and apical points, respectively, with a deviation of 3.5°. The reported accuracy of CAI varied among multiple studies [13].

Various factors can affect the accuracy of implant placement including CBCT data acquisition, intraoral condition transfer (conventional impression or intraoral scan), surgical guided stent manufacturing, improper guided stent fixation and positioning, and the design of a surgical template. Surgical guided stent designs are mainly of two types: multiple [14] and single [15]. In multiple-type stents, the metal-guiding sleeve attached to the surgical stent and coordinating–drilling keys are inserted into the sleeve for guidance purposes during implant preparation. The tolerance of the drilling key to the sleeve and the drills to the drilling key cause deviations of the accuracy in multiple-type stents. Cassetta et al. [15] identified an intrinsic error between the master and inner tubes in single-type stereolithographic–surgical stents. The present study examined a new and modified single-type surgical stent with individual single zirconia sleeves that were incorporated into the surgical stent to fit individual drills by using CAD software.

Accuracy is substantially affected by the tolerance of the gap-drill distance of the sleeve [15], guide sleeve height, drilling distance, drilling key length [16], and surgical sites of the jaw [17]. Kholy et al. [16] demonstrated that reducing the drilling distance or increasing the sleeve height (3 mm) could significantly increase the accuracy of static CAI surgeries. Furthermore, Schneider et al. [18] reported that a greater sleeve height reduced the lateral movement of implant placement and improved overall accuracy. Most relevant studies have reported that imposing more limitations on the guided stent improved the accuracy of implant placement.

Surgeries performed using a CAI template are more accurate than those performed using conventional surgical guides [19]. However, drill sleeve tolerance may directly affect deviation errors during surgery [15,20]. The present study investigated the accuracy of varying drill sleeve distances in multiple positions and the wear conditions between the drill and sleeves. This study hypothesized that the application of small drill-sleeve distance would increase the accuracy of implant installation and induce more wear during surgery.

2. Materials and Methods

2.1. Model Preparation

Fifteen sets of upper and lower partially edentulous epoxy tooling board models, which were milled in the same open CNC (computer numerical control) system milling center (Ardenta CNC mill, DT100-4A, Tainan, Taiwan) with new tungsten–carbide burs, were placed in a Nissin Simple Manikin II (Nissin, Japan) and set on a dental chair to simulate clinical conditions. The missing teeth on these models were the upper right first molars, upper left first molars, lower right first molars, and lower left first molars. An experienced right-handed surgeon prepared implants for the present study by following implant surgical protocol (Figure 1).

Digital wax-ups of the missing teeth and ideal implant installation planning were performed using CAD software (exocad DentalCAD; exocad GmbH). A total of 30 single-type CAD/CAM-guided stents (3 mm thickness) were fabricated using clear PMMA materials and zirconia sleeves (4 mm height) for missing tooth areas. Three internal tubes with different drill sleeve distances (3.61, 3.62, and 3.63 mm) (Figure 2) were designed to fit their respective drills (3.6 mm diameter, Axiom REG, Anthogyr, Sallanches, France) at four partially edentulous areas. In total, 60 new drills with 60 guide sets were prepared in the present study.

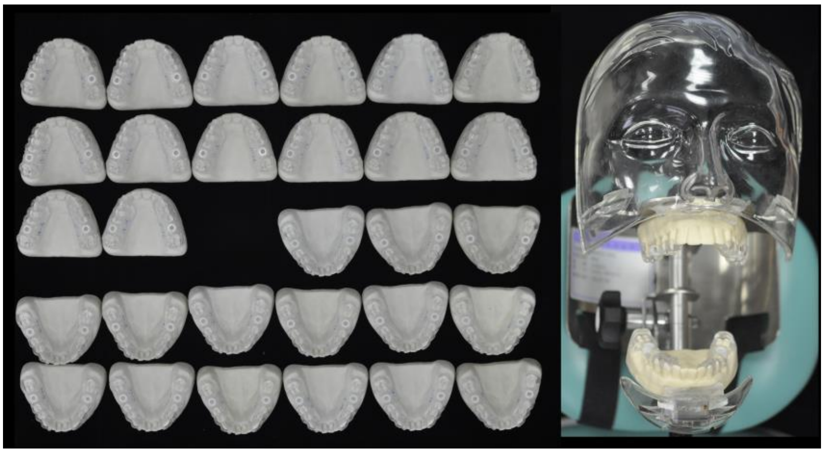

Figure 1. Simulated clinical position and the guided stents on epoxy tooling board model.

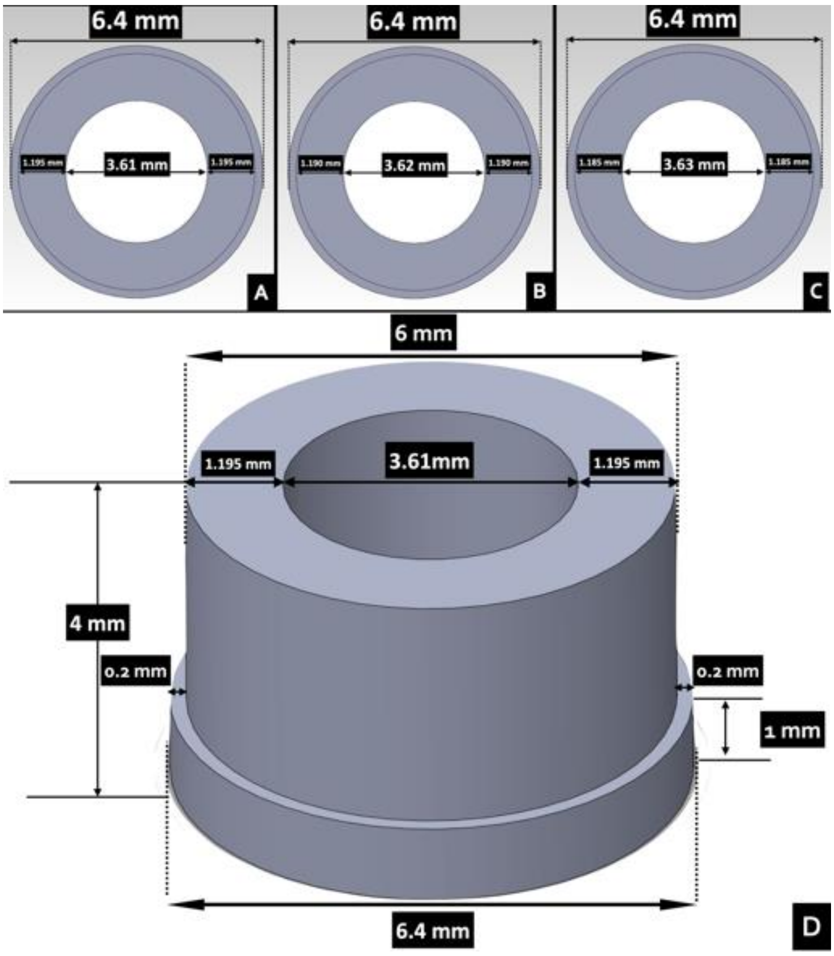

Figure 2. Design of zirconia sleeve: (**A**) 3.61 mm inner tube distance, 1.195 mm sleeve wall thickness; (**B**) 3.62 mm inner tube distance, 1.190 mm sleeve wall thickness; (**C**) 3.63 mm inner tube distance, 1.185 mm sleeve wall thickness; (**D**) 4 mm sleeve height and external diameter of tube is 1 mm height, 6.4 mm sleeve width on occlusal side, 6 mm sleeve width on tissue side.

2.2. Implant Placement

Sixty new drills (3.6 mm in diameter and 10 mm in length) were sequentially drilled into missing tooth areas in the following order: right maxilla, left maxilla, left mandible, and right mandibular sites. After the preparation was completed, all drills were evaluated using a 3D optical profilometer (Bruker, German; Figures 3 and 4) to examine wear conditions, and internal tubes were observed using an EM-2.5D semi-automatic series specification (MIMN TAIY, Taiwan; Figure 5). The maximum height (Sz) is a roughness parameter defined as the sum of the largest peak-height and valley-depth values (ISO 25178). The time of drilling was calculated, and images were compared to evaluate the effect of the drill sleeve distance. CBCT was performed for 60 preparation modes, and their images were superimposed with virtually planned positions to compare horizontal, vertical, and angle deviations (Figure 6).

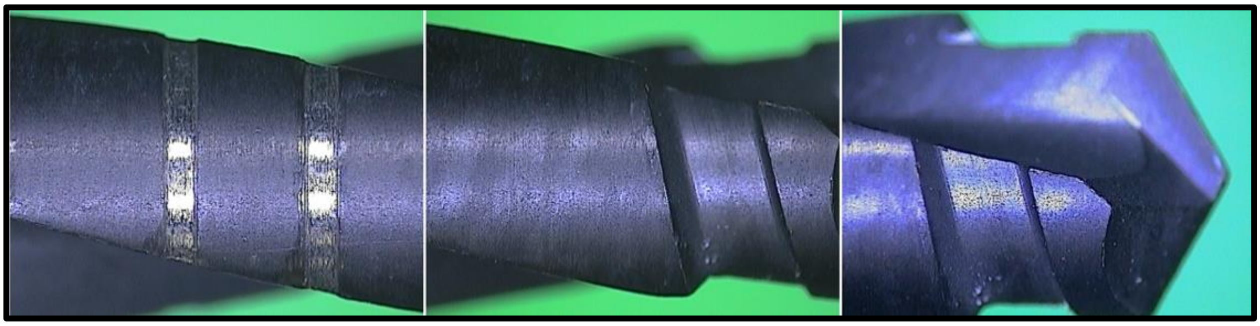

Figure 3. The whole drill was surveyed using 3D optical profilometer, and the wear roughness of drills was investigated on the widest part of the drill.

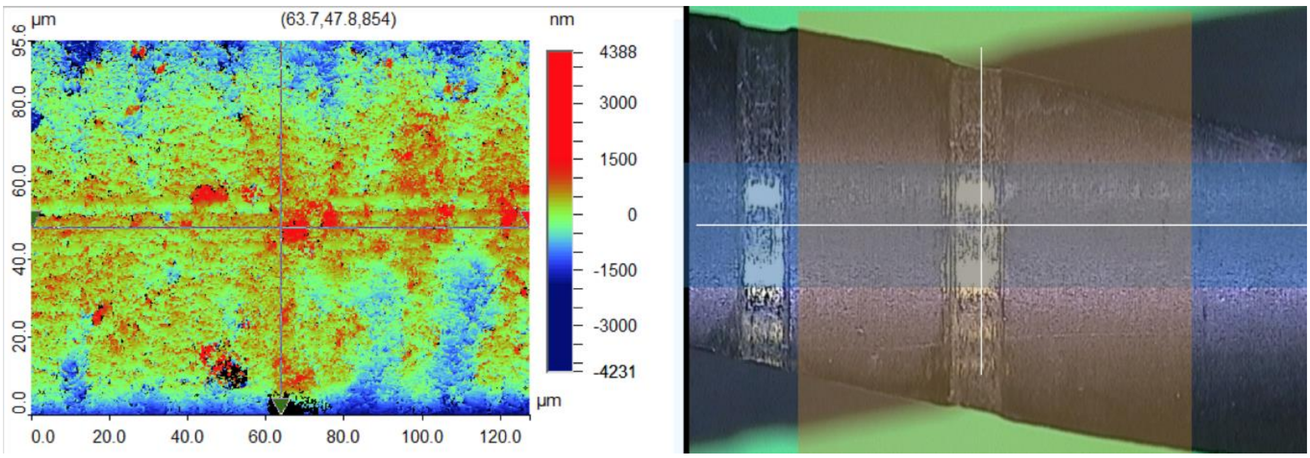

Figure 4. Evaluation of the wear roughness of drills by determining the maximum height (Sz).

2.3. Statistical Analysis

All statistical analyses were conducted using IBM SPSS (SPSS Statistics for Windows, v20; IBM, Armonk, NY, USA). Collected data were exported to an Excel sheet and analyzed using the Kruskal–Wallis equality-of-population rank test. A p-value of <0.05 was considered to be statistically significant.

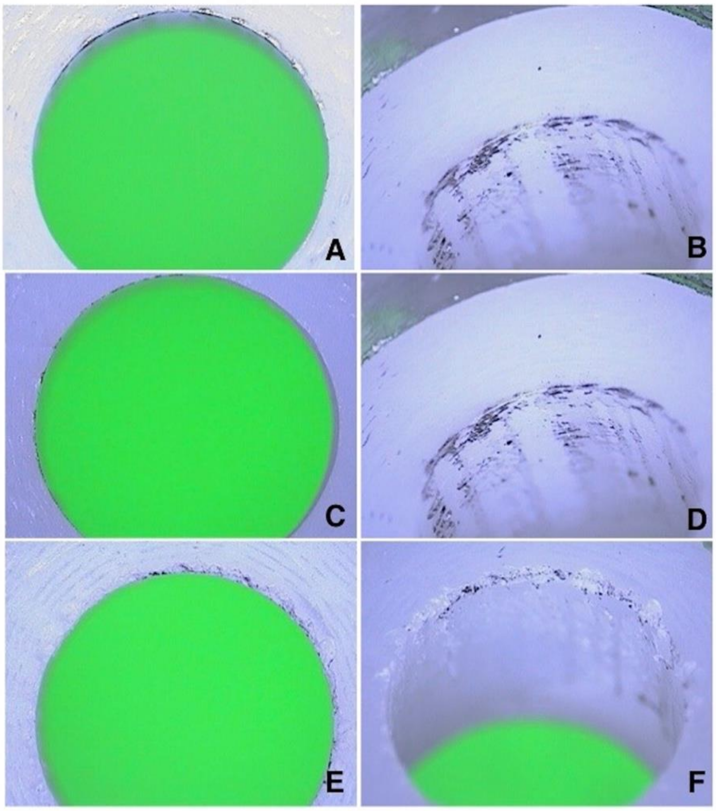

Figure 5. Green background and different wear of zirconia sleeves for the three drill-sleeve distances of (**A**,**B**) 0.01 mm, (**C**,**D**) 0.02 mm, and (**E**,**F**) 0.03 mm was shown via using an EM-2.5D semi-automatic series specification. The 0.03 mm showed more wear among three distances.

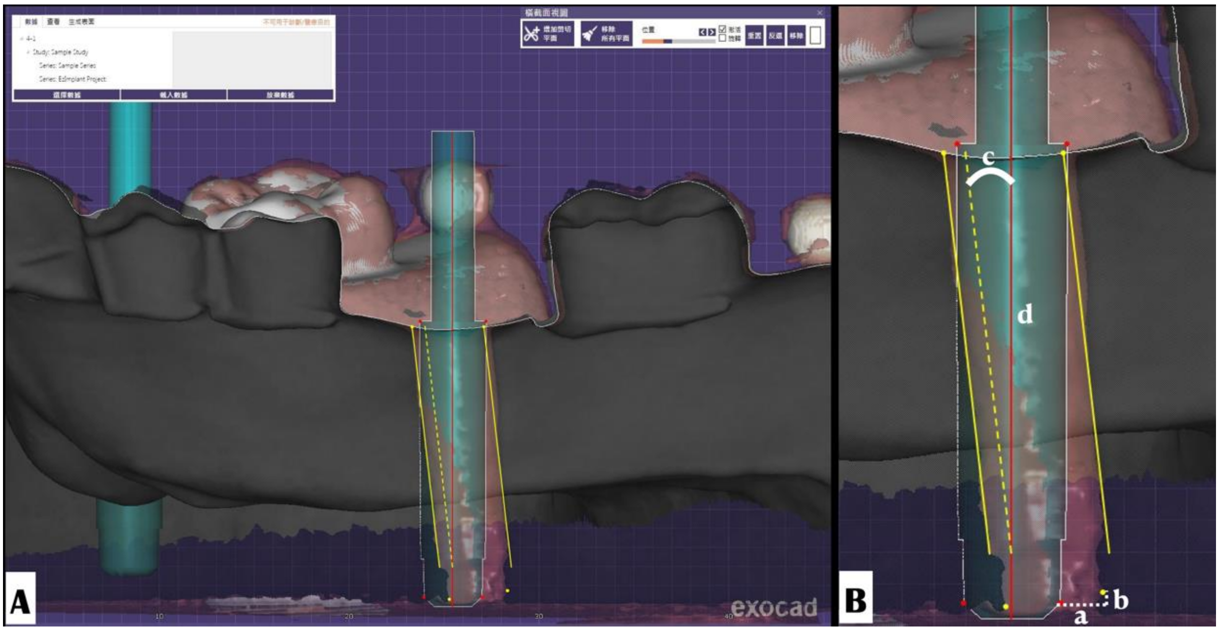

Figure 6. (**A**) Superimposition of the virtual plan and postsurgical position; measurement of points and angle deviations are based on the reference line. (**B**) a: horizontal deviation measurement between red dots (reference point) and yellow dots (postsurgical point); b: vertical deviation measurement; c: angulation deviation measurement; d: reference line (red line): the central axis of ideal implant position.

3. Results

Table 1 lists the deviations of the implant installation with respect to multiple tooth positions and varying drill sleeve distances. The results of 60 analyzed cases revealed horizontal, vertical, and angular deviations. The maximum horizontal deviations did not significantly differ among the three drill sleeve distances (0.01 mm, 0.21 ± 0.17 mm; 0.02 mm, 0.21 ± 0.18 mm; and 0.03 mm, 0.26 ± 0.19 mm; p = 0.603). The maximum vertical deviations did not significantly differ among the three gap distances (0.01 mm, 0.59 ± 0.38 mm; 0.02 mm, 0.72 ± 0.36 mm; and 0.03 mm, 0.86 ± 0.51 mm; p = 0.145). The angular deviations did not significantly differ among the three gap distances (0.01 mm, 2.1° ± 2.15°; 0.02 mm, 3.17° ± 2.45°; and 0.03 mm, 3.92° ± 1.87°; p = 0.046). A wider gap distance was associated with an increased tendency of the occurrence of accuracy errors. The upper-right first molar site exhibited the highest horizontal deviation among the four quarter sites (p < 0.001). The lower left first molar site exhibited the highest vertical value (p = 0.001) and angular deviation (p < 0.001).

Table 1. Deviations of implant installation for multiple drill sleeve distances and positions.

	Maximum Horizontal Deviation (mm)		**Maximum Vertical Deviation (mm)**		**Angulation (°)**	
Varies	**M ± SD**	***p***	**M ± SD**	***p***	**M ± SD**	***p***
Position		<0.001 *		0.001 *		<0.001 *
16 (n = 15)	0.48 ± 0.12 [a]		0.5 ± 0.32 [c]		3.33 ± 2.28 [f]	
26 (n = 15)	0.14 ± 0.07 [b]		0.77 ± 0.51 [ce]		1.98 ± 1.52 [fh]	
36 (n = 15)	0.12 ± 0.08 [b]		1.08 ± 0.35 [de]		5.61 ± 1.21 [g]	
46 (n = 15)	0.13 ± 0.07 [b]		0.6 ± 0.24 [c]		1.44 ± 1.38 [h]	
Distance		0.603		0.145		0.046 *
0.01 (n = 20)	0.21 ± 0.17		0.59 ± 0.38		2.1 ± 2.15 [i]	
0.02 (n = 20)	0.21 ± 0.18		0.72 ± 0.36		3.17 ± 2.45 [ij]	
0.03 (n = 20)	0.26 ± 0.19		0.86 ± 0.51		3.92 ± 1.87 [j]	

Superscript letters in the columns indicate statistical significance among groups (* p < 0.05; Kruskal–Wallis equality-of-population rank test, posthoc Dunn's multiple comparison test).

Table 2 presents the operation time and wear results for multiple drill sleeve distances and positions. Drilling time did not differ significantly among the three drill sleeve distances (p = 0.970) and anatomical sites (p = 0.627). Drill wear did not differ significantly among the three drill sleeve distances (p = 0.677) and anatomical sites (p = 0.791). However, compared with other positions, the positions of 16 and 46 exhibited higher mean values for the maximum height (8.34 and 8.88 μm, respectively) related to drill roughness.

Table 2. Operation time and implant surface wear for multiple drill sleeve distances and positions.

	Time (s)		**Sz (μm)**	
Varies	**M ± SD**	***p***	**M ± SD**	***p***
Position		0.627		0.791
16 (n = 15)	20.67 ± 2.84		8.34 ± 1.64	
26 (n = 15)	20.86 ± 2.13		8.17 ± 1.58	
36 (n = 15)	20.17 ± 3.11		7.81 ± 1.40	
46 (n = 15)	20.29 ± 2.59		8.88 ± 2.62	
Distance		0.970		0.677
0.01 (n = 20)	20.46 ± 2.66		8.04 ± 1.78	
0.02 (n = 20)	20.52 ± 2.63		8.17 ± 1.46	
0.03 (n = 20)	20.50 ± 2.75		8.70 ± 2.29	

Kruskal–Wallis equality-of-population rank test; p < 0.05 indicates statistical significance.

Sz is the sum of the maximum peak height and maximum valley depth.

4. Discussion

The present study examined single-type surgical stents with varying CAD/CAM zirconia drill sleeve distances to determine the accuracy and wear conditions in simulated clinical positions. Tahmaseb et al. [8] conducted a systematic review and reported a mean deviation of 0.9 to 1.2 mm and 3.3° angular deviation for partially edentulous cases. Moreover, the results of accuracy were affected from various tooth positions; the upper right first molar exhibited the maximum horizontal deviation, and the lower left first molar exhibited the maximum vertical and angular deviations.

Drill sleeve distance did not affect horizontal and vertical deviations; however, the maximum angular deviation was observed after the application of a drill sleeve distance of 0.03 mm. Tang et al. [7] reported that the various quadrants of a surgical site produced varying implant deviations in a free-hand placement protocol; their results indicated that the maxilla site (first and second quadrants) was associated with a significant buccolingual angulation and apical point deviation, and the third quadrant was associated with a significant mesiodistal angulation deviation. A systematic review [21] reported a greater angular deviation of implant placement performed using a guided stent for the maxilla than the mandible. This finding can be attributable to the inadequate stability of the guided stent for placement in the fully edentulous maxilla, thus resulting in accuracy errors.

To the best of our knowledge, no study has examined single tooth-gap implantation by using a guided stent. The findings of our in vitro study partially correspond to those of previous studies. Our results indicate that the maximum horizontal deviation of the upper right first molar can be attributable to the impaction of the surgical position by the right-handed surgeon. Kapoor et al. [22] reported that left-handed dental students found the maxilla to be more difficult to operate on than the mandible, with Quarter I being the most challenging to work on. The lower left first molar exhibited a significant difference in vertical and mesiodistal angulation deviations in our study; this could be related to the surgical habits of the right-handed surgeon who worked visually from the anterior–mesial side to the posterior–distal side, resulting in drilling deviations despite the restriction of the pathway by the static-guided stent.

Horwitz et al. [23] demonstrated that the multiple-use sleeve causes sleeve-wall attrition, thus increasing implant deviation. Cassetta et al. [24] indicated that a higher tolerance to system components is associated with the presence of larger intrinsic errors in a system. The present study demonstrated that a distance range of 0.01 to 0.03 mm for drill sleeves did not affect horizontal and vertical deviations. A narrower sleeve (i.e., 0.01 mm) has the advantage of providing the minimal angular deviation of im-plantation; the disadvantage of a narrower sleeve is that it may produce overheating during drill-sleeve contact. However, more sleeve wear (Figure 5) was found in a bigger drill-sleeve distance (i.e., 0.03 mm); this could be relevant to the greater tolerance for deviated drill side cutting the sleeve.

Drill sleeve contact during implant surgery may increase the wear debris, causing unfavorable results such as poor wound healing or osteointegration failure [25]. Koop et al. [26] advised clinicians to move the drill in and out of the guide multiple times to identify the smoothest drill position and allow sufficient irrigation. Shneider et al. [18] demonstrated that the tolerance of surgical instruments and lateral drill movements can be significantly reduced with the application of 3D printing to achieve a decreased sleeve diameter.

Ozan et al. [27] recommended using zirconia as the sleeve material because of better biocompatibility and less sleeve wear. The presented study examined single-type stents with a zirconia sleeve incorporated in one stent. Zirconia is a manufacturing-friendly and easily accessible material in clinical dentistry. CNC milling or 3D printing can be utilized to produce surgical templates with zirconia sleeves that are cost-efficient and can be easily modified for various surgical instruments. The limitations of the present study are as follows. The effects of the clinical saliva and tongue were not simulated and examined. Furthermore, no assistant was assigned to double check the positions.

The results would have benefited from larger sample sizes for all edentulous areas. The authors will compare between single- and multiple-type surgical stents in a future clinical study.

5. Conclusions

The results indicated that adjusting the drill sleeve distance (0.01–0.03 mm) did not significantly affect horizontal and vertical deviations ($p > 0.05$). The drill wear did not differ significantly among three drill sleeve distances ($p = 0.627$); however, the maximum angular deviation ($3.92^\circ \pm 1.87^\circ$) was observed after the application of a drill sleeve distance of 0.03 mm. In practice, a single-type CAD/CAM zirconia-guided stent was recommended. The optimal drill sleeve distance for guided stents should be 0.01 mm.

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