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The Accuracy of Implant Placement According to the Height of the Surgical Guide Hole

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Purpose: This study investigated the impact of the guide hole height on the accuracy of implant placement using CAD/CAM-fabricated surgical guides in resin models. The hypothesis is that decreasing the height of the guide hole reduces placement accuracy. **Materials and Methods:** Ten identical partially edentulous maxillary models were each fitted with surgical guides featuring guide hole heights of 1 mm, 3 mm, and/or 5 mm. Using a surgical guide and drill kit, implants were placed in six predetermined sites per model. Placement accuracy was evaluated by comparing the actual implant positions with the planned positions using digital scanning and computer software analysis. Statistical analyses were performed using ANOVA and Kruskal-Wallis tests to determine the significance of deviations at both the coronal and apical positions. **Results:** The average deviations were 0.75±0.33 mm at the coronal position and 1.10±0.51 mm at the apical position. Placement accuracy did not differ with different guide hole heights. Additionally, errors were consistent regardless of the guide hole height and were not influenced by the type of support or the implant placement site. **Conclusion:** In this rotro study, varying the height of the guide hole did not significantly affect the accuracy of implant placement. The results suggest that guide hole height within the tested range does not have a substantial impact on placement errors. Our findings indicate that factors other than the guide hole height may play a more critical role in implant placement accuracy. [J Korean Dent Sci. 2024;17(4):201-9]

Key Words: Dental implants; Surgical guide

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Introduction

The primary objective of dental implant placement is to achieve optimal positioning within the alveolar bone without compromising esthetics and minimizing the risk of surgical complications[1]. To achieve this, the implant surgical guide must provide the practitioner with a minimal margin of error and a robust and stable drill insertion path[2]. With advances in CAD/CAM, cone-beam computed tomography (CBCT), and three-dimensional imaging technology in implantology, the clinical use of 3D guide templates is increasing. Importantly, the accuracy of implant placement generally improves with the use of guide templates[3]. During surgical procedures, the stability of the guide may be adversely affected by patient factors, such as the implant position, the number of remaining teeth, oral soft tissue conditions, and limited mouth opening[4]. The differences in guide designs and drill kits have also been shown to impact the accuracy of implant placement[5].

Limited surgical access within the oral cavity is frequently cited as the most common issue in implant guide surgery. Therefore, recent digital technological advancements have allowed for various guide designs that aim to position the guide hole as close to the alveolar crest as possible and to reduce the height of the guide hole. This attempts to address the restricted space available for instrument manipulation, especially in the posterior molar region, even at the maximum mouth opening. One solution is to shorten the guide hole. However, this increases the difficulty of controlling final placement errors[6]. A longer guide hole is assumed to be beneficial for minimizing implant placement errors, but due to the constraints of the intraoral environment, the length cannot be extended indefinitely[7]. Furthermore, the correlation between the guide hole height and placement stability has shown varied results across different studies[6,7].

This study aimed to investigate the placement accuracy of implants on resin models using surgical guides fabricated with CAD/CAM and varying guide hole heights. The research hypothesis proposes that "the accuracy of implant placement will decrease as the height of the guide hole decreases."

Materials and Methods

The study protocol involved placing six implants using CT and intraoral scan data (Fig. 1). Ten identical partially edentulous maxillary models, with tissue support on the right side and tooth support on the left side, were fabricated via 3D printing. The surgical guides were designed as a single-piece that includes both sides using digital software and produced with a Stereolithography Apparatus (SLA) 3D printer (Form 3+, Formlabs, Somerville, MA, USA) using surgical guide resin (Fig. 2). The guide holes were designed with heights of 1 mm, 3 mm, and 5 mm. The heights varied among the ten models, with one side at 1 mm and the other at 3 mm, or one side at 3 mm and the other at 5 mm, resulting in a total of five experimental groups (Fig. 3).

In each model, six implants of identical diameter (4.0 mm) and length (10.0 mm) were placed in the six implantation sites using the R2GATE® surgical kit (Megagen Implant, Daegu, Korea). Model was placed on a stationary table and sequential drilling was done according to the manufacturer's instructions. To verify the position of the placed fixtures, a scan body was attached to the top of each fixture. Subsequent scanning provided digital data that allowed for the verification of the fixture positions. These digital data were then matched with the pre-implantation planning data using ProPlan CMF 3.0 (Materialise, Leuven, Belgium). To compare the post-experiment scanned data with the pre-implantation design, manual registration was performed using the aligning tool in aforementioned software. Scan data of remained dentition were used to align the data with the original CT scans. The center points at the top and bottom of each fixture were used as references for measuring the placement error relative

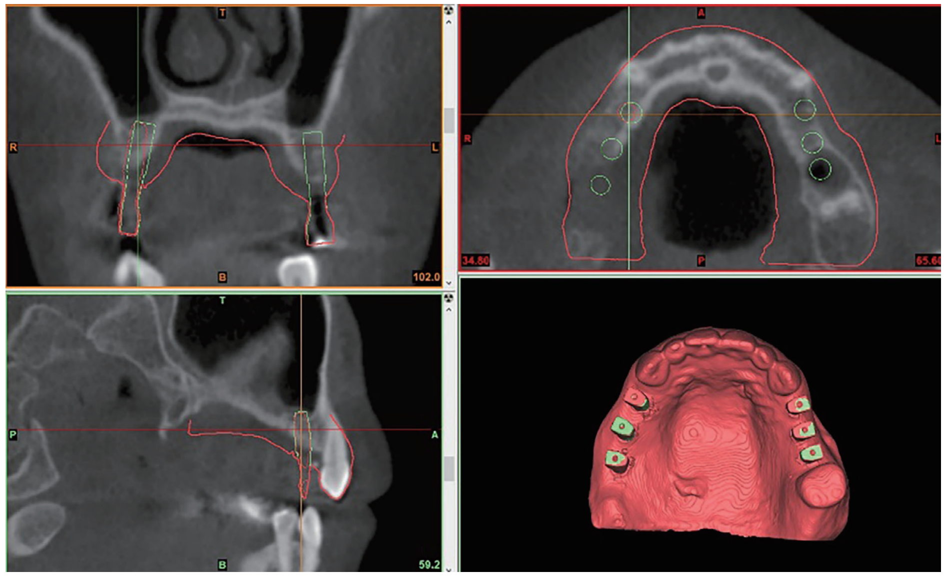

Fig. 1. CT images of the digital surgical plan for implant placements. The optical scan data represent the bilateral edentulous area for the placement of six implants and post-experimental state of placed implants and connected scan bodies.

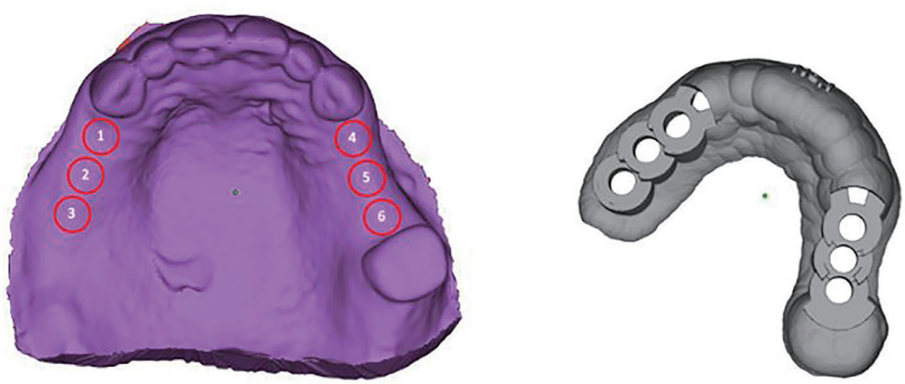

Fig. 2. The maxillary partial edentulous model and the fabricated surgical guide used for the study. The six implant placement sites and surgical guides are designed virtually and fabricated using 3-D printing.

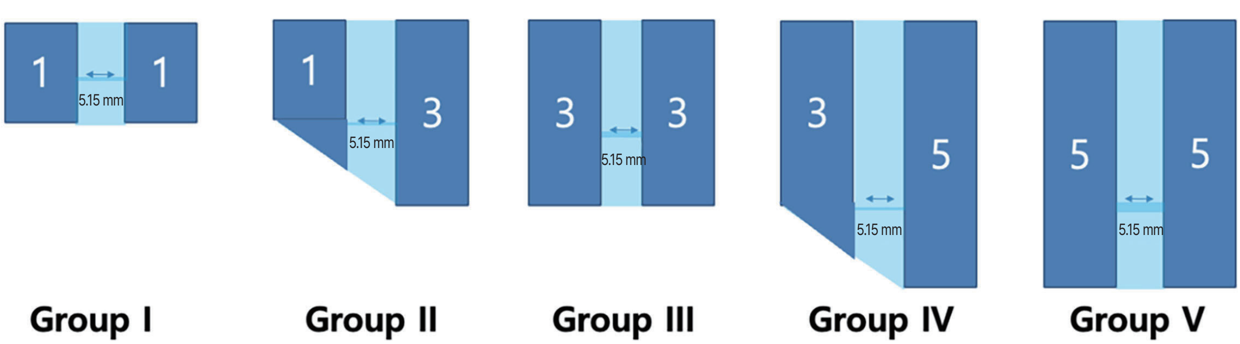

Fig. 3. Five experimental groups, set up according to the heights (mm) of the guide holes between one and five millimeters. The height of both sides of Group II and Group IV are differentially assigned. The height difference is randomized across the left and right sides.

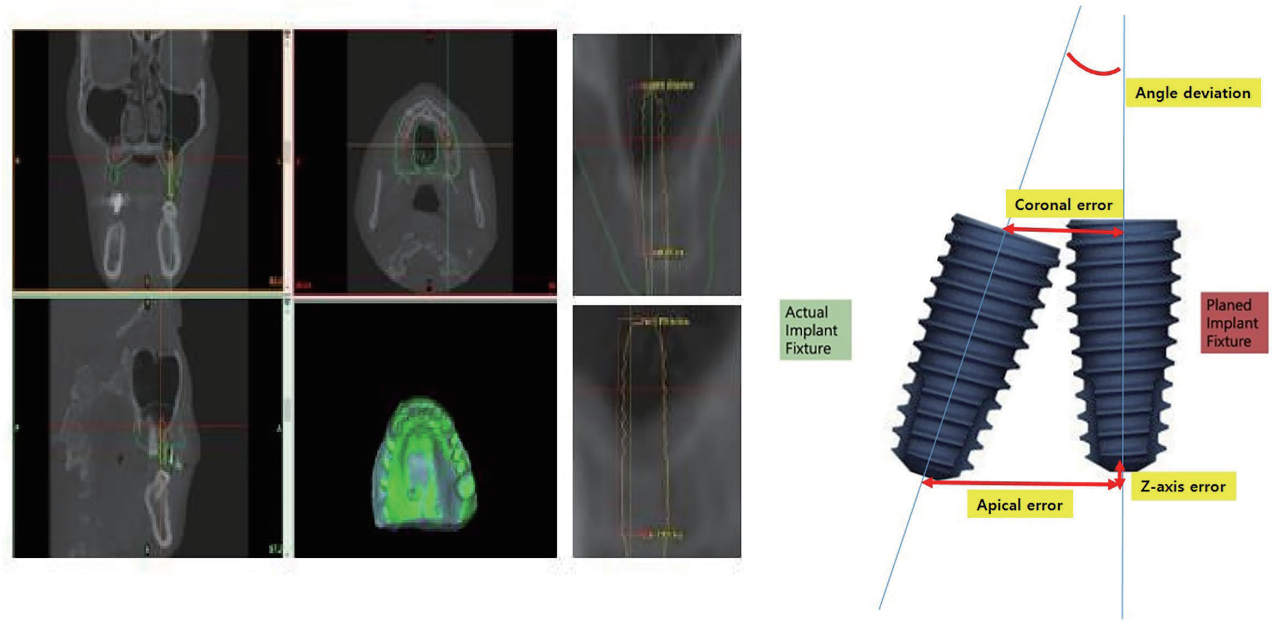

Fig. 4. Superimposition of the digital planning data and digital data of the placed implants. Differences between the planning data versus the surgery data are calculated using computer software.

to the planned data (Fig. 4). Statistical analysis was performed using SPSS, version 27.0 (SPSS, Chicago, IL, USA). Analysis of variance (ANOVA) and Kruskal-Wallis tests were conducted. Statistical significance was set at $P<0.05$.

Results

In this study, the three-dimensional linear distances between the placed implants and the planned implants at the coronal position (top) and apical position (bottom) were measured. The average distance was 0.75±0.33 mm at the coronal position and 1.10±0.51 mm at the apical position, with no significant differences observed between the groups (Table 1 and 2). Furthermore, when the error distances were divided into mesiodistal deviation, buccopalatal deviation, and implantation depth (the z-axis), no significant

Table 1. Three-dimensional deviations of the implants at the coronal position

Group	Coronal deviation (mm)				
	n	Mean±SD	F[a]	P[b]	Post-Hoc[c] (Games-Howell)
I	12	0.79±0.31			
II	12	0.83±0.27			
III	12	0.84±0.45	1.279	0.289	-
IV	12	0.59±0.24			
V	12	0.68±0.31			
Total	60	0.75±0.33			

[a] A higher F-value indicates a greater difference between the experimental groups.
[b] By one-way ANOVA test.
[c] No statistical significance at post-hoc analysis.

Table 2. Three-dimensional deviations of the implants at the apical position

Group	Apical deviation (mm)				
	n	Mean±SD	F[a]	*P*[b]	Post-Hoc[c] (Games-Howell)
I	12	1.26±0.53	1.620	0.182	-
II	12	1.25±0.41			
III	12	1.17±0.64			
IV	12	0.85±0.41			
V	12	0.96±0.45			
Total	60	1.10±0.51			

[a] A higher F-value indicates a greater difference between the experimental groups.
[b] By one-way ANOVA test.
[c] No statistical significance at post-hoc analysis.

differences were observed between the groups at the coronal and apical positions (Table 3 and 4). There was no significant differences between groups at the angular deviations (Table 5). Results between the free-end edentulous areas and the areas with bilateral tooth support from the guide did not differ significantly. Additionally, no significant differences were detected among the six implant placement sites.

Table 3. Two-dimensional deviations of the implants at the coronal position

Group	Coronal deviation (mm)		
	Mesiodistal[a] (mean±SD)	Buccopalatal[a] (mean±SD)	Axis[a] (mean±SD)
I	0.40±0.36	0.65±0.43	0.34±0.18
II	0.53±0.39	0.73±0.71	0.37±0.28
III	0.59±0.46	0.53±0.45	0.44±0.24
IV	0.52±0.38	0.85±0.55	0.42±0.26
V	0.48±0.42	0.56±0.51	0.38±0.25

[a] By Kruskal-Wallis test. There was no statistically significant difference.

Table 4. Two-dimensional deviations of the implants at the apical position

Group	Apical deviation (mm)		
	Mesiodistal[a] (mean±SD)	Buccopalatal[a] (mean±SD)	Z-Axis[a] (mean±SD)
I	0.55±0.46	1.31±0.87	0.33±0.20
II	0.67±0.54	0.83±0.62	0.35±0.24
III	0.74±0.57	0.75±0.61	0.47±0.26
IV	0.58±0.40	0.69±0.69	0.43±0.30
V	0.66±0.56	0.85±0.55	0.37±0.30

[a] By Kruskal-Wallis test. There was no statistically significant difference.

Table 5. Angular deviations of the implants

Group	Angular deviation (°)				
	N	Mean±SD	F[a]	*P*[b]	Post-Hoc[c] (Games-Howell)
I	12	1.28±1.04	0.759	0.556	-
II	12	1.23±1.24			
III	12	1.67±0.95			
IV	12	0.99±0.62			
V	12	1.20±0.95			
Total	60	1.27±0.97			

[a] A higher F-value indicates a greater difference between the experimental groups.
[b] By one-way ANOVA test.
[c] No statistical significance - post-hoc analysis.

Discussion

Virtual implant planning and guided surgery is on the rise. It is recommended as standard treatment for complex and challenging cases[8]. Implants placed using surgical guides fabricated through digital scans can achieve high accuracy in the planned implant position and orientation[9]. Numerous studies have examined the accuracy of implant placement using surgical guides. As an in vitro investigation, this study has some inherent limitations compared to clinical research. However, it is advantageous for controlling various factors. Therefore, this study aimed to evaluate the accuracy of implant placements with varying guide hole heights under controlled conditions. Saini et al. conducted a systematic review and reported that the use of stereolithographic surgical templates in dental implant placement showed average placement errors of 0.97±0.37 mm at the coronal position and 1.13±0.36 mm at the apical position[10]. Similarly, Chai et al. reported an average placement error of 1.53±0.48 mm at the coronal position and 1.58±0.49 mm at the apical position in guided surgeries for edentulous patients[11].

Compared to the systematic review by Tahmaseb et al., which reported errors between 1.12 mm and 1.39 mm, our study demonstrated superior results[12]. The average error of the 60 implants placed in our models was 0.75±0.33 mm at the coronal position and 1.10±0.51 mm at the apical position, indicating a lower error range compared to that reported in previous clinical studies. The more favorable results in this study, despite using guide hole heights (1 - 5 mm) that were shorter than those typically used in clinical studies, may be attributed to various clinical factors. In terms of the direction of error, the buccolingual deviation was found to be the largest, compared to the mesiodistal deviation, these findings suggest that controlling buccolingual deviations may be more challenging, particularly in the posterior regions, where limited access and guide stability may contribute to increased errors.

Implant guides are classified into tooth-supported, mucosa-supported, and bone-supported types. In clinical surgeries, mucosa-supported and bone-supported guides can be challenging to align correctly due to the elasticity and thickness of the gingival mucosa and the interference of the gingival flap[13,14]. Ozan et al. found that the angular deviation of implants placed with three different types of guides was 2.91°±1.3°, 4.63°±2.6°, and 4.51°±2.1°, respectively, with higher placement errors in mucosa-supported and bone-supported implants[15]. This was attributed to the micromovement of the guide caused by the flexibility of the soft tissue. Furthermore, the expansion of the gingival mucosa due to local anesthesia can affect the fit of the guide template[16]. In this study, implants were placed in 3D-printed models without artificial gingiva, and the use of a guide covering the entire arch is thought to have resulted in lower errors. The lack of significant errors by region, as well as the presence or absence of teeth on both sides of the guide, may also be due to the use of a sufficiently rigid guide design supported by multiple teeth.

When mouth opening is limited, it can hinder the proper fit of the guide template and the accessibility of the drill. These issues are particularly problematic in the posterior molar regions. For example, with limited space, extreme angulation of the drill may occur, leading to increased placement errors[17-19]. Moreover, tension from the lips and buccal muscles can cause the guide template to shift anteriorly and the drill head to be pushed palatally, resulting in the drill tip rotating buccally and causing mesiodistal and buccolingual placement errors[16]. Furthermore, errors related to the direction of placement can also occur due to the surgeon's dominant hand[20]. Conversely, in this study, no significant differences were observed in the errors in either the buccopalatal or mesiodistal directions, as implant placements were performed on models rather than in a clinical setting.

Operator-dependent differences in placement accuracy should also be considered. Guided surgery is designed to overcome the limitations of traditional placement methods and limited surgical experiences. However, even in guided surgery, the accuracy of implant placement can vary depending on the surgeon's experience[21]. Guided surgery is associated with a learning curve. Under the same clinical conditions, less experienced surgeons tend to show greater deviations in the buccolingual direction and placement depth[22]. A previous study reported an average difference of 1.5° in buccolingual angulation errors between experienced and inexperienced surgeons, with the experienced group showing significantly lower placement errors[23]. In this study, the experiments were conducted by a single operator with approximately 10 years of experience in using guides, which may have contributed to fewer errors.

Choi et al. identified the guide hole height as a key determinant in controlling the angular deviation during implant placement, and suggested that a longer guide hole is essential for reducing placement errors[7]. A previous study reported that implant placement errors increased when the guide hole height was 5 mm or less[24]. In contrast, other studies found no significant differences in the placement accuracy of varying guide hole heights (4 mm and 8 mm)[6]. Similarly, in this study, the placement errors did not differ significantly among the groups with varying guide hole heights (5 mm or less).

While the guide hole height alone did not significantly affect the 3D accuracy of implant positioning, the free drilling distance, defined as the linear distance from the bottom of the guide hole to the drill tip, was associated with a significant increase in both 3D and angular deviations as the distance increased[25]. For instance, using a 24 mm drill with a 2 mm guide hole height is expected to result in a longer free drilling distance and greater 3D deviation compared to using a 20 mm drill with a 6 mm guide hole height[25]. Therefore, the guide hole height is not the only factor affecting implant placement accuracy. Instead, the guide hole height and the drill length may be both critical in determining implant placement accuracy. This study was conducted in an in vitro setting with numerous factors being controlled. To verify these results and identify the clinical factors associated with placement errors, well-designed clinical studies are necessary.

Conclusion

The three-dimensional linear distance between the placed implants and the planned implants averaged 0.75±0.33 mm at the coronal position and 1.10±0.51 mm at the apical position, with no significant differences observed between the groups. In an in vitro environment, where clinical factors leading to errors are controlled, a reduction in the guide hole heights did not result in significant differences in implant placement accuracy.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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