In Vitro Accuracy of Static Guided Implant Surgery Measured by Optical Scan: Examining the Impact of Operator Experience

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Abstract: Studies examining the effect of operator experience on the accuracy of static guided implant surgery have used postoperative computed tomography (CT) images to measure the error, with inconsistent results. The purpose of this study was to try to clarify this issue by using a measurement method based on the postoperative optical scan. Thirty dentists were divided into an experienced group and an inexperienced group. On a partially edentulous mandibular model in the manikin head, each dentist placed three implants via the stereolithographic (SLA) surgical guide. The implant positions were identified by a desktop scanner and compared with the planned positions using a metrology software program. No statistically significant differences were observed for any of the measured positional and angular deviations of the three implant sites between experienced and inexperienced operators (p > 0.01). All the mean values of deviations of the inexperienced group, except the depth deviation, were less than the experienced group. Implants inserted by dentists under 40 years old had significantly better accuracy than senior doctors in the global deviation at implant apex (p = 0.006). Within the limits of this study, we concluded that operator experience is not a critical factor in achieving the accuracy of guided implant surgery via the tooth-supported SLA surgical guide. Large deviations could occur even with the aid of the SLA surgical guide, and care must be taken to avoid errors for both experienced and inexperienced operators.

Keywords: stereolithographic surgical guide; optical scan; 3D-planning; accuracy; computer-aided design/computer-aided manufacturing (CAD/CAM); guided implant surgery; operator experience

1. Introduction

Computer-guided implant surgery has gained popularity because it helps surgeons to plan and place dental implants efficiently [1], for which two types of techniques have been advocated:
static (template-based) and dynamic navigation [2]. Nowadays, the static approach is more popular because high-cost equipment is not needed. A virtual implant treatment plan can be performed using three-dimensional planning software and transferred to the patient by using computer-aided design and computer-aided manufacturing (CAD/CAM) surgical guides during implant surgery. The static guided implant surgery can help surgeons to achieve ideal implant position and avoid damaging surrounding anatomical structures [3]. Moreover, a proper implant position and angulation is essential for long-term success in terms of biomechanics and esthetics. To accomplish this treatment concept, a key determinant is the accuracy of the computer-guided implant placement [4].

In the literature, the accuracy of computer-guided implant surgery had been widely examined and compared [1,5,6]. Conventionally, these studies used the method of overlapping the pre- and postoperative computed tomography (CT) images to measure the deviations of the placed implant [7,8]. The problem of this CT matching method is that the outline of the postoperative implant could be ambiguous due to the artifacts produced from the titanium implant material. The overall implant contour could be enlarged, making the correct identification of the implant geometry difficult [9].

A different method for examining the accuracy using the optical scan has been described [9]. Although commonly applied to the accuracy studies, the CT matching method was reported to be less accurate than the CAD/CAM-based measurement method by scanning the abutment placed on the implant with an intraoral scanner [10].

Many steps are involved in the static guided implant surgery, from the evaluation and collection of clinical data of the patient to the performance of the surgery. Errors in each step could affect the final accuracy of the implant placement. Among these factors, the surgeon’s technical skills and experience are apparently influential [11]. Studies have shown that computer-guided implant placement is more accurate than nonguided or freehand implant placement [1,3,5,12,13]. Thus, the effect of operator experience in static guided implant surgery was of particular interest; if inexperienced doctors could perform static computer-guided implant placement as accurately as experienced doctors, this protocol should be highly recommended for clinicians with limited implant surgery experience. However, the effect of operator experience on the accuracy of static guided implant surgery remains an issue to be clarified. In the literature, the results are not consistent [14], and almost of all the studies have used the CT matching method to examine implant placement accuracy.

To clarify the inconsistent results in the literature, another assessment method of the accuracy should be used considering the limitations of the CT matching method. The purpose of the present study, therefore, was to examine the influence of operator experience on the accuracy of static guided implant surgery, by using the optical scan to capture the postoperative implant position for the error measurement. In order to exclude the possible confounding factors associated with clinical trials, in vitro simulation implant surgeries performed on dental models were used for better control of the study variables.

2. Materials and Methods

2.1. Operator Enrollment

This study was executed at the School of Dentistry, Health Sciences University of Hokkaido (HSUH), Hokkaido, Japan. Two groups of dentists, according to their experiences on dental implant surgery, were recruited from different departments of the School of Dentistry of HSUH. The inclusion criterion for the experienced group was dentists who had performed more than twenty guided implant surgeries; for the inexperienced group, it was dentists who had more than two years’ experience of dental practicing yet had never placed dental implants in a patient. Fifteen dentists for each group were enrolled according to a priori sample size calculation.
2.2. Implant Planning and Surgical Guide Fabrication

The materials and the procedures of the simulation implant placement have been described previously [15]. In brief, a urethane partially edentulous mandibular model (Nissin Dental Model P9-X.1523-L, Nissin Dental Products Inc., Kyoto, Japan) was selected as a master model to fabricate the surgical guide. The model, together with a radiographic template converted from the wax-up of the missing teeth, was sent to take a CT scan. Using an implant planning software (BioNa®, Wada Precision Dental Laboratories Co. Ltd., Osaka, Japan), three Kyocera POIEX 3.7 × 10 mm implants (Kyocera Medical Co. Osaka, Japan) were virtually planned based on the Digital Imaging and Communication in Medicine (DICOM) files of the CT scan. Accordingly, a surgical guide was designed and six stereolithographic (SLA) surgical guides were manufactured by a dental laboratory (Wada Precision Dental Laboratories Co. Ltd., Osaka, Japan) with the same settings (3 mm thickness and 0.03 mm guide-to-teeth offset) (Figure 1).

![Figure 1](https://example.com/figure1.png)

*Figure 1.* (a) The mandibular model used for the study. (b) Three implants were virtually planned at the missing molar positions. (c) The finished stereolithographic (SLA) surgical guide.

2.3. Simulation Implant Placement

Every model used for simulation implant placement was screened from surface geometry comparison by matching its optical scan image with the master model. Aside from the interdental undercut area, only the models with a surface discrepancy of less than 0.05 mm were selected (Figure 2). The mandibular model and its opposing maxillary model were attached to the manikin secured on a laboratory bench. The distance between maxillary and mandibular central incisors was set to 47 mm according to a study on the maximum mouth opening of Asian ethnicity [16]. (Figure 3)

The procedural information of the guided-implant surgery was explained to the dentists before the model surgery. Through the inspection window, the correct seating of the surgical guide was confirmed. In the manikin head, every dentist placed three implants (Kyocera POIEX 3.7 × 10 mm, Kyocera Medical Co.) on a model via the SLA surgical guide with the guided surgical kit (Bone Navi System, Wada Precision Dental Laboratories Co. Ltd., Osaka, Japan), following the instructions of the manufacturer.
2.4. Deviation Measurement

After implant placement, titanium scan bodies (GEO CAD, Geomedi Co., Ltd., Fukuoka, Japan) were connected to the placed implants and the model was scanned with a desktop model scanner (inEos X5, Sirona Dental Systems GmbH, Bensheim, Germany). These digital datasets, along with the CAD files of the implant and the scan body, were uploaded into a CAD software program (Geomagic Design X, 3D Systems Inc., Rock Hill, SC, USA) so that the placed implant position could be verified in the software (Figure 4).

Figure 2. Comparison of the 3D surface scans of each model. (a) Aside from the interdental spaces with undercuts, only the models with a surface discrepancy of less than 0.05 mm (green area) were selected. (b) Models with surface discrepancies larger than 0.05 mm (yellow or blue area) were excluded.

Figure 3. (a) Mouth opening of the manikin was set to 47 mm. (b) Laboratory setting of the simulation guided implant surgery.

Figure 4. (a) Simulation implant placement performed on the model fixed to the manikin. (b) Scan body connected to the placed implant. (c) Implant position verified in the CAD software.
The digital data of the virtual implant planning and the model were also exported in a Standard Tessellation Language (STL) format to the same CAD software. The pre- and postoperative model images were then superimposed. The digital images of each planned and placed implants could be isolated, and the center of the implant platform/apex, and the implant axis connecting the two center points could be calculated and determined by the software. The superimposed pre- and postoperative model images were then imported to a metrology software program (Geomagic Control X, 3D Systems Inc.), and the deviations between planned and placed implants of each implant site were measured for the accuracy analysis.

The subsequent three-dimensional and angular deviations were measured: global deviation at the implant platform/apex, lateral deviation at the implant platform/apex, depth deviation, and angular deviation. The global deviation was the three-dimensional distance between the center of the implant platform/apex of planned and placed implants. The angular deviation was the three-dimensional angle between the planned and placed implant axis. The lateral deviation and the depth deviation were divided from the global according to the axis of the planned implant (Figure 5). Figure 6 presented a schematic diagram of the summarized workflow of the accuracy assessment.

![Figure 5](image.png)

**Figure 5.** Definitions of the deviations measured at the implant platform: (a) global deviation, (b) lateral deviation, (c) depth deviation, and (d) angular deviation. The identical coordinate system (blue arrows) was used to measure the deviations at the implant apex.

![Figure 6](image.png)

**Figure 6.** Summarized workflow of the accuracy assessment.
2.5. Statistical Analysis

According to a sample size calculation from a pilot study using effect size 0.5, 80% power, and 5% \( \alpha \)-error, the sample size of 15 for each operator experience group is sufficient, and was hence adopted for this study. Quantitative data were described as mean values, standard deviation, and range. Box plots were drawn to show the distribution of the deviation data. For continuous variables, the Wilcoxon rank sum test, the two-sample t-test, and the analysis of variance (ANOVA) were used for the statistical analyses. The Chi-squared and Fisher’s exact tests were used for categorical variables. The \( p \) value and \( t \) value of the t test were corrected by the Satterthwaite method if unequal variances in two groups. For adjusting the covariance by operators, we also used analysis of covariance (ANCOVA) for further examination. The significance level was adjusted to 0.01 with a Bonferroni method. The STATA 14 statistics software (StataCorp, College Station, TX, USA) was used for statistical analysis.

3. Results

The demographic description and the specialty of the 30 participants are presented in Table 1. The mean age of the inexperienced group (40.1 ± 7.5) was 5.4 years younger than the experienced group (45.5 ± 9.4). The experienced group had 6.7 years more of mean dental practicing years (20.1 ± 10.3) than the inexperienced group (13.4 ± 7.1); however, the differences were not significant. Only two of the dentists were female. All the participants used their right hand as the dominant hand (one dentist used to be left-handed, but he changed his dominant hand to the right hand). In the experienced group, almost half of the dentists came from the fixed prosthodontics and implantology department; four came from the oral and maxillofacial surgery department, and one from the periodontal department. However, more of the inexperienced dentists came from the other departments, including clinical cariology, removable prosthodontics, and pediatric dentistry.

Table 1. Demographics and specialty of the participants.

| Operator Group | Dentist Number | Age | Gender | Years of Practicing | Specialty |
|----------------|----------------|-----|--------|---------------------|-----------|
|                |                |     | Male   | Female              |            |
| Total (Range)  | 30             | 42.8 ± 8.8 (30–59) | 28 | 2 | 16.8 ± 9.3 (2–35) | 10 8 12 |
| Experienced (Range) | 15 | 45.5 ± 9.4 (32–59) | 15 | - | 20.1 ± 10.3 (2–35) | 7 5 3 |
| Inexperienced (Range) | 15 | 40.1 ± 7.5 (30–54) | 13 | 2 | 13.4 ± 7.1 (5–30) | 3 3 9 |

\( p \) Value: Wilcoxon rank sum test for continuous variables; chi-squared and Fisher’s exact test for categorical variables.
Fixed Pros: fixed prosthodontics and implantology; OS: oral and maxillofacial surgery; Perio: periodontics.

The deviations between planned and placed implants for all of the implants in both of the experienced and inexperienced operator groups are presented and compared in Table 2. For all 90 implants, the mean global deviation was 0.71 ± 0.39 mm at the implant platform, and 1.20 ± 0.87 mm at the implant apex. The mean lateral deviation was 0.50 ± 0.36 mm at the implant platform, and 1.06 ± 0.87 mm at the implant apex. The mean depth deviation was 0.41 ± 0.33 mm, and the mean angular deviation was 3.44 ± 3.00°.

In the comparison between the experienced and inexperienced operator groups, no significant differences were found for any positional or angular deviations, even after adjusting the covariance between an individual operator and his experience. Except for the depth deviation, in which the mean value of the experienced operator group was almost the same as the inexperienced group (0.40 and 0.42 mm, respectively), the experienced operator groups had higher mean values of the other positional and angular deviations compared to the inexperienced operator groups (Table 2).
Table 2. Deviations between planned and placed implant position, by operator experience.

| Operator Experience Group | Implant Number | Implant Platform | Implant Apex | Depth Deviation (mm) | Angular Deviation (Degree) |
|---------------------------|----------------|-----------------|-------------|---------------------|---------------------------|
|                           |                | Global           | Lateral      | Global           | Lateral      | Global           | Lateral      |              |              |
| Total (range)             | 90             | 0.71 ± 0.39     | 0.50 ± 0.36  | 1.20 ± 0.87     | 1.06 ± 0.87  | 0.41 ± 0.33     | 3.44 ± 3.00  |              |              |
| Experienced (range)       | 45             | 0.74 ± 0.36     | 0.54 ± 0.37  | 1.30 ± 0.93     | 1.17 ± 0.96  | 0.40 ± 0.29     | 3.86 ± 3.43  |              |              |
| Inexperienced (range)     | 45             | 0.68 ± 0.42     | 0.47 ± 0.34  | 1.09 ± 0.79     | 0.94 ± 0.77  | 0.42 ± 0.37     | 3.02 ± 2.47  |              |              |
| p Value a                 | 0.4824         | 0.48 ± 0.41     | 0.50 ± 0.42  | 1.24 ± 0.88     | 1.09 ± 0.93  | 0.49 ± 0.26     | 3.57 ± 2.97  |              |              |
| p Value b                 | 0.8014         | 0.67 ± 0.43     | 0.44 ± 0.28  | 1.17 ± 0.77     | 1.02 ± 0.72  | 0.45 ± 0.39     | 3.41 ± 2.51  |              |              |

To examine the potential influence of different implant sites on the accuracy, all the positional and angular deviations were further evaluated according to each implant site group, and the results are presented in Table 3. Still, no significant differences were found between experienced and inexperienced operators for any of the measured deviations at the three implant sites, and most of the mean values of deviations of the inexperienced operator groups were less than the experienced groups.

Table 3. Deviations between planned and placed implant position according to implant site.

| Operator Experience Group | Implant Number | Implant Platform | Implant Apex | Depth Deviation (mm) | Angular Deviation (Degree) |
|---------------------------|----------------|-----------------|-------------|---------------------|---------------------------|
|                           |                | Global           | Lateral      | Global           | Lateral      | Global           | Lateral      |              |              |
| Left first molar          |                |                 |             |                    |              |                 |              |              |              |
| Experienced               | 15             | 0.74 ± 0.41     | 0.48 ± 0.42  | 1.24 ± 0.88     | 1.09 ± 0.93  | 0.49 ± 0.26     | 3.57 ± 2.97  |              |              |
| Inexperienced             | 15             | 0.67 ± 0.43     | 0.44 ± 0.28  | 1.17 ± 0.77     | 1.02 ± 0.72  | 0.45 ± 0.39     | 3.41 ± 2.51  |              |              |
| p Value ‡                | 0.6662         | 0.5338          | 1.0000       | 0.8357           | 1.0000       | 0.3195          | 1.0000       |              |              |
| p Value ¶                | 0.9810         | 0.9872          | 0.6170       | 0.5206           | 0.5366       | 0.3278          |              |              |

Right first molar          |                |                 |             |                    |              |                 |              |              |              |
| Experienced               | 15             | 0.72 ± 0.38     | 0.51 ± 0.33  | 1.39 ± 1.03     | 1.24 ± 1.03  | 0.43 ± 0.34     | 4.26 ± 4.06  |              |              |
| Inexperienced             | 15             | 0.77 ± 0.53     | 0.51 ± 0.44  | 1.21 ± 0.96     | 1.01 ± 0.95  | 0.52 ± 0.39     | 2.97 ± 2.97  |              |              |
| p Value ‡                | 0.9669         | 0.9697          | 0.6482       | 0.6187           | 0.5614       | 0.6187          | 0.4553       |              |              |
| p Value ¶                | 0.8010         | 0.9872          | 0.6170       | 0.5206           | 0.5366       | 0.3278          |              |              |

Right second molar         |                |                 |             |                    |              |                 |              |              |              |
| Experienced               | 15             | 0.75 ± 0.32     | 0.63 ± 0.37  | 1.28 ± 0.94     | 1.17 ± 0.99  | 0.29 ± 0.24     | 3.74 ± 3.38  |              |              |
| Inexperienced             | 15             | 0.60 ± 0.29     | 0.45 ± 0.28  | 0.90 ± 0.63     | 0.80 ± 0.64  | 0.30 ± 0.29     | 2.69 ± 1.94  |              |              |
| p Value ‡                | 0.1833         | 0.1000          | 0.2121       | 0.2285           | 0.9549       | 0.3056          |              |              |
| p Value ¶                | 0.1354         | 0.7509          | 0.2455       | 0.2998           | 1.0000       | 0.6783          |              |              |
| ANOVA p Value †           | 0.8723         | 0.7509          | 0.2455       | 0.2998           | 1.0000       | 0.6783          |              |              |

† p Value: Student’s t test of two operator experience groups of each implant site, ANCOVA p Values not shown due to similar results. ‡ p Value: Wilcoxon rank sum test of two operator experience groups of each implant site. ¶ p Value: ANOVA test of six implant sites and operator experience groups.

The distributions of the measured deviations for experienced and inexperienced operators are correspondingly presented in the box plots in Figures 7–9. Generally speaking, no significant disparity was observed between experienced and inexperienced operators in terms of the positional deviations at the implant platform (Figures 7a and 8a), and the depth deviations (Figure 9a) of each implant site. However, for the positional deviations at the implant apex (Figures 7b and 8b) as well as the angular deviations (Figure 9b), implants placed by experienced operators tended to have larger deviations than inexperienced operators, especially at the right first molar and right second molar sites.
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Figure 7. Box plots of the global deviation at implant: (a) platform and (b) apex of experienced and inexperienced operator group.

Figure 8. Box plots of the lateral deviation at the implant: (a) platform and (b) apex of experienced and inexperienced operator group.

Figure 9. Box plots of the (a) depth deviation and (b) angular deviation of experienced and inexperienced operator group.

Table 4 compares the differences of the measured deviations according to the operator’s age, years of the dental practice, and specialty. The operator’s age was found to have a significant influence on accuracy. The operator group of under 40 years old had smaller deviations in every measured
deviation than the other two age groups. Except for the depth deviation, the differences were significant ($p = 0.0068$ for the global deviation of implant apex) or marginally significant ($p$ values around 0.01) for the other measured deviations. No significant differences could be observed for the years of dental practice and the specialty of the operators. The distributions of the measured deviations according to the operator’s age groups were presented in the box plots in Figures 10–12.

### Table 4. Deviations between planned and placed implant position according to operator variables.

| Operator Variables | Implant Number | Implant Platform Global (mm) ± | Lateral (mm) ± | Implant Apex Global (mm) ± | Lateral (mm) ± | Depth Deviation (mm) ± | Angular Deviation (Degree) ± |
|--------------------|----------------|--------------------------------|----------------|---------------------------|----------------|------------------------|----------------------------|
| Total              | 90             | 0.71 ± 0.39                    | 0.50 ± 0.36     | 1.20 ± 0.87               | 1.06 ± 0.87   | 0.41 ± 0.33             | 3.44 ± 3.00                |
| Age                |                |                                |                |                           |                |                        |                            |
| ≤39                | 39             | 0.57 ± 0.21                    | 0.38 ± 0.17     | 0.87 ± 0.39               | 0.74 ± 0.41   | 0.36 ± 0.25             | 2.40 ± 1.38                |
| 40–49              | 27             | 0.85 ± 0.47                    | 0.60 ± 0.40     | 1.46 ± 0.94               | 1.29 ± 0.92   | 0.50 ± 0.42             | 4.12 ± 3.12                |
| ≥50                | 24             | 0.77 ± 0.46                    | 0.59 ± 0.46     | 1.43 ± 1.16               | 1.30 ± 1.19   | 0.39 ± 0.32             | 4.36 ± 4.19                |
| p Value ‡          |                | 0.0111                         | 0.0175          | 0.0068 *                  | 0.0101        | 0.2207                 | 0.0144                     |
| Gender             |                |                                |                |                           |                |                        |                            |
| Male               | 84             | 0.72 ± 0.40                    | 0.52 ± 0.36     | 1.22 ± 0.89               | 1.08 ± 0.90   | 0.41 ± 0.33             | 3.52 ± 3.09                |
| Female             | 6              | 0.60 ± 0.29                    | 0.30 ± 0.18     | 0.88 ± 0.28               | 0.67 ± 0.27   | 0.45 ± 0.37             | 2.38 ± 0.87                |
| p Value ‡          |                | 0.4716                         | 0.091           | 0.452                     | 0.3608        | 0.728                  | 0.728                      |
| Years of practice  |                |                                |                |                           |                |                        |                            |
| ≤10                | 33             | 0.74 ± 0.43                    | 0.50 ± 0.35     | 1.17 ± 0.82               | 1.00 ± 0.80   | 0.47 ± 0.37             | 3.16 ± 2.55                |
| 11–20              | 24             | 0.58 ± 0.30                    | 0.42 ± 0.26     | 0.99 ± 0.65               | 0.88 ± 0.66   | 0.33 ± 0.27             | 2.91 ± 2.39                |
| ≥21                | 33             | 0.77 ± 0.41                    | 0.57 ± 0.41     | 1.37 ± 1.02               | 1.24 ± 1.05   | 0.41 ± 0.32             | 4.11 ± 3.71                |
| p Value ‡          |                | 0.1465                         | 0.2939          | 0.2562                    | 0.2828        | 0.2952                 | 0.261                      |
| Specialty          |                |                                |                |                           |                |                        |                            |
| Fixed Pros.        | 30             | 0.64 ± 0.30                    | 0.42 ± 0.31     | 1.05 ± 0.72               | 0.89 ± 0.77   | 0.41 ± 0.23             | 2.94 ± 2.66                |
| O&S/Perio.         | 24             | 0.68 ± 0.38                    | 0.49 ± 0.37     | 1.19 ± 1.00               | 1.06 ± 1.01   | 0.36 ± 0.32             | 3.62 ± 3.63                |
| Others             | 36             | 0.78 ± 0.46                    | 0.58 ± 0.37     | 1.33 ± 0.88               | 1.19 ± 0.86   | 0.44 ± 0.40             | 3.74 ± 2.85                |
| p Value ‡          |                | 0.3278                         | 0.2145          | 0.4219                    | 0.377         | 0.6598                 | 0.5291                     |

† $p$ Value: ANOVA test, * $p < 0.01$, ‡ significant difference by Tukey multiple comparisons. ‡ $p$ Value: Wilcoxon rank sum test. Fixed Pros: fixed prosthetics and implantology; O&S: oral and maxillofacial surgery; Perio: periodontics.

![Figure 10](a) ![Figure 10](b)

**Figure 10.** Box plots of the global deviation at implant: (a) platform and (b) apex of the three operator age groups.
4. Discussion

To the best of our knowledge, this was the first study to use the optical-scan-based measurement method to investigate the influence of operator experience on the accuracy of static guided implant surgery. The results of this study revealed that for mandibular partial edentulism of molars, inexperienced dentists could place dental implants as accurately as experienced operators under a well-controlled environment. However, even with the help of the surgical guide, large deviations can still occur for both experienced and inexperienced operators, suggesting the operator’s skill and attention during surgery was crucial for accurately executing static guided implant surgery.

In the literature, there is little consensus regarding the influence of operator experience on the accuracy of static guided implant surgery. Cushen et al. [17] reported a significant difference between experienced and inexperienced operators for both angular and horizontal errors at the implant apex and platform using the SLA surgical template on edentulous mandibular models. They concluded that more experienced operators place implants more accurately. Hinckfuss et al. [18] reported significantly less angulation error in the buccal–lingual direction for experienced operators utilizing tooth-supported surgical guides, yet no significant difference in positional errors was found between experienced and inexperienced operators. A similar result was reported by Fernandez-Gil et al. in a model study using a tooth-supported guide [8]. Rungcharassaeng et al. [19] used mandibular models with bilateral second premolars missing and carried out tests with the tooth-supported guide. No significant angular nor linear deviation was found between the experienced and inexperienced groups. Nevertheless,
they reported the depth of guided implant placement was most influenced by the operator’s level of experience.

Although the studies mentioned above reported a better accuracy for experienced operators in static guided surgery, the results did not coincide with each other with regard to the influence of operator experience on the dimension of the errors.

On the other hand, Park et al. [20], in their model experiment using tooth-supported guides found the operator’s experience level had no significant influence on the accuracy in guided implant surgery. In addition, Van de Wiele et al. [21], in a clinical report on fully edentulous jaws, concluded that inexperience of the surgeon did not influence the accuracy when they were under the supervision by experienced surgeons. Another clinical study by Cassetta et al. [22] also demonstrated the limited influence of experience on the accuracy of guided implant placement on edentulous patients.

All of the abovementioned studies exploring the relationship between operator experience and accuracy used the CT matching method to measure the errors, except for one study by Hinckfuss et al. [18], which used a coordinate measuring machine to record the implant coordinates. However, they found only minimum effect of the operator experience on the accuracy of implant placement, and the magnitude of error was not large enough to be clinically significant.

To avoid potential errors from estimating the vague implant outline of the CT data, the present study used the optical scan to identify the postoperative implant position. Most of the accuracy studies of guided implant surgery used cone beam computed tomography (CBCT) images for CT matching. Al-Ekrish and Ekram [23] investigated the CBCT images of human skulls and found a mean error of 0.49 mm between CBCT and direct measurements. Considering the limitations of measurement by CT matching, the present study provided additional evidence to clarify the effect of operator experience on the accuracy of static guided implant surgery. The results of the present study demonstrated that operator experience is not a crucial factor for achieving the implant placement accuracy via tooth-supported SLA surgical guides. Further in vivo studies, preferably under the supervision of experienced doctors, are needed to validate this finding.

From another standpoint, Marie et al. [24] investigated the clinical accuracy of implant positioning using a partially guided protocol instead of a fully guided implant placement. They concluded the level of surgeon experience affected the accuracy of the implant positioning via a tooth-supported surgical guide. In a similar in vivo study, Bencharit et al. [25] also suggested that experience and training may play an important role in guided surgery. Indeed, using a partially guided surgical protocol, the surgeon must understand the treatment plan thoroughly and place the implant freehand. Therefore, the surgical training and experience of the surgeon are crucial for appropriately executing the implant surgery, which may not be so significant for fully guided implant placement in terms of accuracy, such as in the present study.

In this study, we had tried to adjust the covariance between individual performances of the dentists and their level of experience, and the levels of significance were almost the same after the statistical adjustment. Personal skill or performance was not easy to quantify. Nevertheless, in our study, a sample size of 15 with 80% power was enough to detect the association between individual performance and experience. Large positional and angular deviations were found in both experienced and inexperienced groups; hence, based on considerable variation in the deviation values among the operators in both experienced and inexperienced groups, human error in executing the simulation surgery, rather than experience, was reasonably inferred to be a significant factor contributing to the more substantial errors of some operators. Furthermore, although not statistically significant, the mean values of the deviations of the inexperienced group were generally smaller than the experienced group in this study. This trend has also been noticed in a clinical report [21]. The large apical and angular deviations appeared more in the experienced groups, possibly meaning that the inexperienced operator could be paying more attention to following the instructed procedures than the experienced operators, because of their lack of experience.
We also found that the operator’s age had a significant influence on accuracy. Younger dentists had better performance than senior doctors, regardless of their experiences on the static guided implant surgery. To date, all the studies examining the impact of operator experience on static guided implant surgery focused only on the experience level of the dentist, but not the age, probably because senior doctors were naturally regarded as experienced. In the present study, however, dentists with varying ages and specialties were recruited in both experienced and inexperienced groups. Therefore, we could examine the effect of the demographics of the dentist on the accuracy of static guided implant surgery.

For dynamic computer-guided navigation systems, junior dentists or dental students were reported to have better performance in terms of the accuracy of implant placement [26,27]; however, we did not find similar studies for the static guided implant surgery in the literature. The effect of age on the accuracy of static guided implant surgery remains an issue to be clarified.

Another finding of this study was that, even under well-controlled laboratory conditions, significant errors could still occur when placing implants via the SLA surgical guide. For static guided implant surgery, multiple steps were involved, and errors could take place in any of the steps from the acquisition of patient data to the execution of surgery [1]. In the literature, relatively high maximum deviations were also revealed [3,4,13,28], which coincided with the results of this study. The present study was conducted in the laboratory and, hence, the influence of variables typically associated with clinical trials should be minimal; however, great variation in deviations was seen among operators. Similar results were reported in a model study [29], in which even the simulation was performed on a bench top instead of in the manikin head.

In this study, we have attempted to control the influential variables as much as possible. The edentulous part of the models was constructed in two layers to mimic the structure of cortical bone and cancellous bone. All the models were screened by the optical scan to make sure the difference in model surface geometry was negligible. Fernandez-Gil et al. [8] examined the potential wear of the surgical guide using an optical scanner after five simulation surgeries, and no changes of the sleeves were inspected. Based on their findings, in this study, each surgical guide was used for five times only. In addition, using worn drills may affect the apical position of the implant due to flagging of the drills [30]; hence, we provided a brand new final drill for every operator. Therefore, the influence by the materials and instruments used in this study should be minimum. The operators, experienced or not, should keep in mind that large deviations could occur even with the help of the computer guide, and should therefore pay attention to every implant surgery.

The size and the location of the edentulous site were found to significantly affect the accuracy of implant placement via a tooth-supported SLA guide [18,31]. In this study, each dentist placed three implants at different sites of the model in which two were in a distal free-end situation. However, the deviations of the three implant sites showed no significant differences in either the experienced or inexperienced group. For tooth-supported surgical guides, the remaining teeth form a base for the appropriate seating of the guide, which is essential for achieving accurate implant placement. In this study, the guide-to-teeth offset of the surgical guide was set to 0.03 mm, a distance that enabled the guide to be intimately contacted to the dental model. This helped the stabilization of the guide and could reduce the micromovements during the drilling and implant placement procedure. In addition, a supportive strut contacting the distal part of the model at the free-end side was designed [15]. The rigidity of the surgical guide at the free-end side was improved, which may be helpful in achieving accuracy when placing the implants. Further studies are needed to inspect the influence of the implant site and number on the accuracy of static guided implant surgery.

The level of operator experience was difficult to define. Most studies have used the number of implant surgeries instead of the years of practicing to describe operator experience. Rungcharassaeng et al. [19] defined operators who had placed more than 20 implants to be experienced. We considered 20 to be a reasonable number for a surgeon to become acquainted with the procedure; however, we focused the criterion on having performed more than 20 guided implant surgeries, which could be more representative of the operator experience when considering the research goal of this study.
In addition, in the inexperienced group, we recruited the dentists with at least two years of dental practice. The distribution of the demographics and specialty of the operators between the two groups had no statistical difference. Hence, the difference between the two groups should be mainly in the experience of placing implants. However, we could not extend our conclusion to novice dentists who had not much experience both in dental practice and in implant surgery. The qualification of operator experience and the performance of the novice dentists should be further studied in the future.

Another limitation of this study was that we could not examine the learning curve effect, since the performance of the individual surgeon over the period could not be evaluated in this study. Vasak et al. [32] found a learning curve effect over the time period of performance of two experienced surgeons in one clinical study. However, in another clinical study, Cassetta et al. [33] did not find a clear learning curve after examining 227 implants inserted via bone-, tooth-, and mucosa-supported SLA surgical guides. Nevertheless, in a pilot study on a simulation model to examine the learning progress among dental students, Golob Deeb et al. [27] observed a significant improvement in speed and angular accuracy of implant placement using dynamic navigation in the first three implantations. Unfortunately, we did not measure the sequence and time for each implant placement of the operators; hence, the comparison of the improvement within each operator was impossible in the present study. However, the overall deviations of the implants placed in three implant sites were not significantly different from each other, which suggested that such improvement in accuracy might not exist in this study. Whether the learning effect exists in static guided surgery remains an issue to be explored.

Generally speaking, the results of the present study were comparable to most other studies in terms of implant placement accuracy; hence, the inference that operator experience is not essential for achieving the implant placement accuracy should be trustworthy. However, we must keep in mind that accuracy does not equal to success. Although implant position is important for achieving esthetics and proper biomechanics of the final restoration, professional surgical training and the experience of the operators, nonetheless, remain essential for the success of dental implant treatment.

5. Conclusions

Within the limits of the present study, the following conclusions are drawn based on the results of the experimental work:

1. Operator experience is not a critical factor for achieving accuracy of static guided implant surgery when using a tooth-supported surgical guide in a well-controlled environment. The SLA surgical guide aids inexperienced dentists in placing dental implants such that accuracy is comparable to that of experienced surgeons.
2. Large positional or angular deviations of implant placement can occur, even with the aid of the SLA surgical guide and under well-controlled conditions. Care must be taken to avoid errors by appropriately executing the static guided implant surgery for both experienced and inexperienced operators.

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