Comparison of Implant Accuracy between Experienced and Novice Operators Using Dynamic Computer-assisted Implant Surgery in Posterior Region: In Vitro Study

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Abstract

Dental implants are widely used for replacing missing teeth with their success highly dependent on accurate placement. However, the posterior maxilla poses unique challenges due to its anatomical structure and limited visibility. Recently, dynamic computer-assisted implant surgery (dCAIS) systems have been developed to enhance implant placement accuracy and reduce variability caused by operator experience. This study aimed to evaluate the impact of operator experience on implant placement accuracy in the posterior maxilla using dCAIS. This in vitro study included six operators (three experienced and three novice) who placed a total of 30 implants in partially edentulous maxillary models using X-Guide. Postoperative accuracy was evaluated by measuring angular deviation, platform deviation, apex deviation, and depth deviation. Statistical analyses were conducted using independent t-tests to compare the accuracy between the two groups ($P < 0.05$). Experienced operators demonstrated a mean angular deviation of $0.69 \pm 0.53°$, platform deviation of 0.80 ± 0.46 mm, apex deviation of 0.77 ± 0.47 mm, and depth deviation of 0.53 ± 0.48 mm. In contrast, novice operators exhibited a mean angular deviation of $1.06 \pm 0.68°$, platform deviation of 1.14 ± 0.55 mm, apex deviation of 1.15 ± 0.56 mm, and depth deviation of 0.92 ± 0.66 mm. While experienced operators consistently achieved greater precision, the differences between the two groups were not statistically significant ($P > 0.05$). dCAIS effectively supports accurate implant placement in the posterior maxilla, minimizing the influence of operator experience. Both experienced and novice operators achieved clinically acceptable results, highlighting the potential of dCAIS to standardize outcomes across varying skill levels.

Keywords: *dynamic computer-assisted implant surgery, operator experience, dynamic navigation, implant accuracy*

1. Introduction

Dental implants are widely recognized as a treatment of choice for replacing missing teeth due to their high success and survival rates, offering both functional and aesthetic benefits when properly placed (Beikler, & Flemmig, 2015; Pjetursson et al., 2014). The success of dental implants depends not only on achieving osseointegration but also on the precise control of depth, angulation, and crestal position in accordance with a prosthetically driven treatment plan. Accurate implant placement ensures the long-term stability and functionality of implant-retained restorations while minimizing complications. However, achieving such precision is influenced by a variety of factors, including the surgical technique and the experience level of the operator.

The posterior maxilla is often regarded as one of the most challenging areas for dental implant placement due to its unique anatomical, position and biomechanical characteristics (Morand, & Irinakis, 2007). This region typically exhibits poor bone quality with fine trabeculae and thin cortical plates. It compromises primary stability during implant placement (Ananda et al., 2015; Atieh et al., 2010; Smith, & Tarnow, 2013). Additionally, anatomical limitations such as sinus pneumatization, vertical and horizontal alveolar bone resorption, and reduced residual ridge height further complicate the procedure. These challenges are compounded by limited visibility, restricted access, and increased masticatory forces (up to three times greater than those in the anterior maxilla) making implant placement in this region particularly demanding (M. King, & Schofield, 2023). Adjunctive procedures such as sinus lifts or guided bone regeneration are often required to address these limitations, but these techniques introduce additional complexity and potential for complications.

Operator experience is a critical factor that may influence the accuracy of implant placement in the posterior maxilla. Experienced operators tend to be more proficient in approaching the position in this region or managing the anatomical complexities of this region, such as proximity to the sinus floor and reduced bone density. They are also more skilled in performing advanced surgical techniques like sinus augmentation or ridge splitting, which are often necessary for successful implant placement in this area. Studies have shown that experienced operators generally achieve lower angular and linear deviations at both the platform and apex compared to novice operators (Atieh et al., 2010). However, even experienced surgeons face challenges in this region due to its inherent difficulties.

Recent advancements in computer-assisted implant surgery (CAIS), including static and dynamic navigation systems, have significantly improved implant placement accuracy compared to freehand approaches (Kivovics et al., 2022; Pellegrino et al., 2021; Ruppin et al., 2008; Somogyi-Ganss et al., 2015; Yogui et al., 2021). Dynamic CAIS (dCAIS), in particular, provides real-time feedback on drill position during osteotomy via visual imaging tools displayed on a monitor. This allows operators to make intraoperative adjustments to improve precision (Block, & Emery, 2016; Block et al., 2017; Casap et al., 2008). Interestingly, dCAIS has been shown to reduce deviations even for novice operators by compensating for their lack of expertise. However, while CAIS can narrow the gap between experienced and inexperienced clinicians, it does not entirely eliminate the influence of operator skill. For instance, experienced operators may still achieve better outcomes when managing complex cases or adapting to unforeseen intraoperative challenges. Despite these advancements, there is limited evidence directly comparing the accuracy of dental implant placement by experienced versus inexperienced operators specifically in the posterior maxilla.

2. Objectives

To analyze the relationship between operator experience and the accuracy of dental implant placement in the posterior maxilla using dCAIS, with the null hypothesis stating that there is no statistically significant difference in implant placement accuracy between experienced and novice operators.

3. Materials and Methods

This in vitro study assessed the accuracy of dental implant placement in the posterior maxilla using a dynamic computer-assisted implant surgery (dCAIS) system, X-Guide (X-Nav Technologies, LLC, Lansdale, PA). The study was aimed to compare the accuracy of implant placement between experienced and novice operators. A total of 30 implants were placed in partially edentulous maxillary models, with 15 implants allocated to each operator group. The sample size was calculated using G*power 3.1 (Heinrich-Heine Univertat, Dusseldorf, Germany), considering a power of 0.90, a type I error of 5% and a calculated effect size of 1.49, based on previous study (Pellegrino et al., 2020). With 30% compensation for error, the sample size was 15 implants per group (30 implants in total).

Participants included six operators divided into two groups: three experienced operators and three novice operators. Experienced operators were defined as clinicians with extensive clinical experience in implantology, having placed over 20 implants. While novice operators were dental students or clinicians with no prior experience in implant placement (Rungcharassaeng et al., 2015) and both groups had no prior dynamic navigation experience.

The maxillary models were fabricated to simulate partially edentulous areas at tooth position 17 area. Fiducial markers were attached to the buccal side of each model to facilitate navigation tracking during surgery

(Figure 1). Each model was scanned using an intraoral scanner (Trios3; 3Shape A/S) and Cone Beam Computed Tomography (CBCT) imaging (Dentsply Sirona). The collected data were imported into Implant Studio software (3Shape A/S) to create virtual surgical plans. Implants were planned to be positioned 2 mm below the crestal bone level with a safety margin of 1.5 mm from adjacent structures in both bucco-palatal and mesio-distal directions. Straumann BLT implants (⌀4.1 × 10 mm^2; Institute Straumann AG, Basel, Switzerland) were used for all placements. The model was secured on a dental phantom head, and operators were positioned directly behind it to simulate an actual clinical condition. Each operator placed five implants under real-time guidance provided by the X-Guide system, resulting in a total of 30 implants across all participants. All surgeries were conducted in a standardized operating room environment using identical instruments and protocols to minimize external variability.

Postoperative accuracy was evaluated by superimposing preoperative virtual surgical plans onto postoperative CBCT scans using coDiagnostiX software (Dental Wings, Montreal, Canada). The software's built-in treatment evaluation tool automatically calculated deviations between planned and actual implant positions (Figure 2).

Four key parameters were assessed (Figure 3):

1. Angular deviation, defined as the three-dimensional angular difference between the longitudinal axes of the planned and placed implants.
2. Platform deviation, measured as the distance between the coronal centers of the planned and placed implant platforms.
3. Apex deviation, representing the distance between the apical centers of the planned and placed implants.
4. Depth deviation, which quantified vertical discrepancies between planned and placed implant positions.

This methodology ensured a comprehensive assessment of implant placement accuracy while accounting for operator experience and anatomical challenges associated with posterior maxillary implant placement.

Figure 1 The maxillary model with right posterior edentulous area (area tooth 17) with fiducial marker on the buccal side of the left posterior maxilla

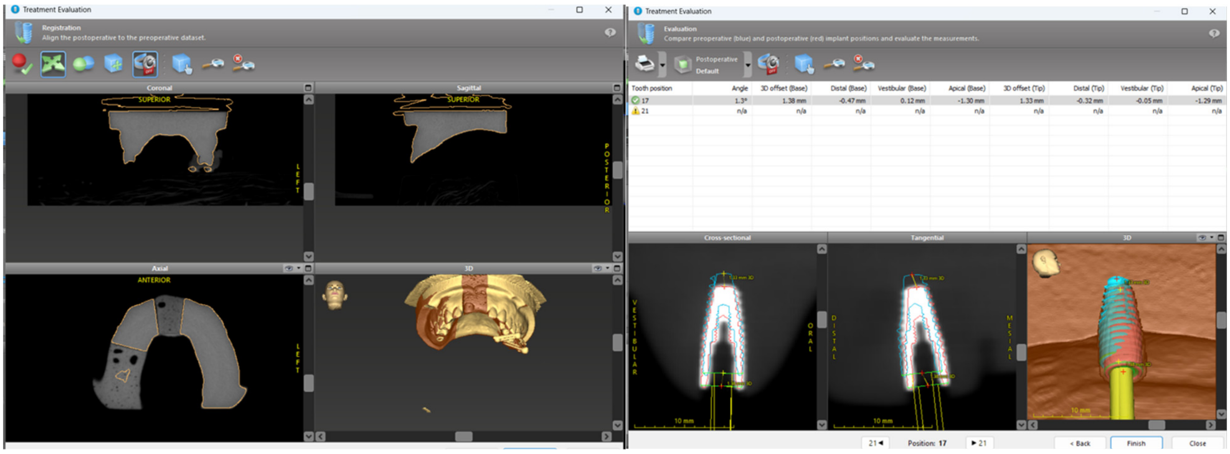

Figure 2 Treatment evaluation tool. The registration process involves aligning the postoperative dataset with the preoperative dataset to ensure accurate comparison and evaluation (right). Representation of the 3D accuracy measurement for implant position. Blue indicates the preoperative implant position, while red indicates the actual implant position (left)

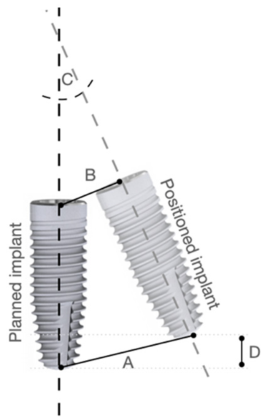

Figure 3 Implant deviation measurement model diagram: (A) apex deviation, (B) platform deviation, (C) angular deviation and (D) depth deviation

Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics for all parameters, including angular deviation, platform deviation, apex deviation, and depth deviation, were reported as mean ± standard deviation (SD). The normality of the data distribution was assessed using the Shapiro-Wilk test. An independent t-test was used to compare the effect of operator experience (experienced and novice operators) on the accuracy of angular deviation, platform deviation, apex deviation, and depth deviation. A p-value of <0.05 was considered statistically significant.

4. Results and Discussion

4.1 Results

In total, 30 dental implants were placed by six operators, comprising three experienced and three novice operators (three male and three female operators). Each operator placed five implants in this study.

The overall mean angular deviation for all operators was 0.88°. The mean platform deviation, apex deviation, and depth deviation were 0.97 mm, 0.96 mm, and 0.72 mm, respectively.

Figure 4 presents the deviations observed in posterior implant placement between the planned and actual implant positions for both experienced and novice operators. Among experienced operators, the mean angular deviation was 0.69 ± 0.53°, while novice operators exhibited a higher mean angular deviation of 1.06 ± 0.68°. Similarly, for platform deviation, experienced operators demonstrated a mean of 0.80 ± 0.46 mm compared to 1.14 ± 0.55 mm in novice operators. Apex deviation followed a similar trend, with experienced operators showing a mean deviation of 0.77 ± 0.47 mm, whereas novice operators exhibited a mean of 1.15 ± 0.56 mm. Depth deviation was notably lower in experienced operators, with a mean value of 0.53 ± 0.48 mm, compared to novice operators, who exhibited a higher mean depth deviation of 0.92 ± 0.66 mm.

Although novice operators consistently exhibited higher deviations across all measured parameters, including angular deviation, platform deviation, apex deviation, and depth deviation, the differences between the two groups were not statistically significant (*P>0.05*). These findings indicate that while experienced operators tended to achieve better precision overall, the variations in accuracy between the two groups were not large enough to be deemed statistically significant within the conditions of this study.

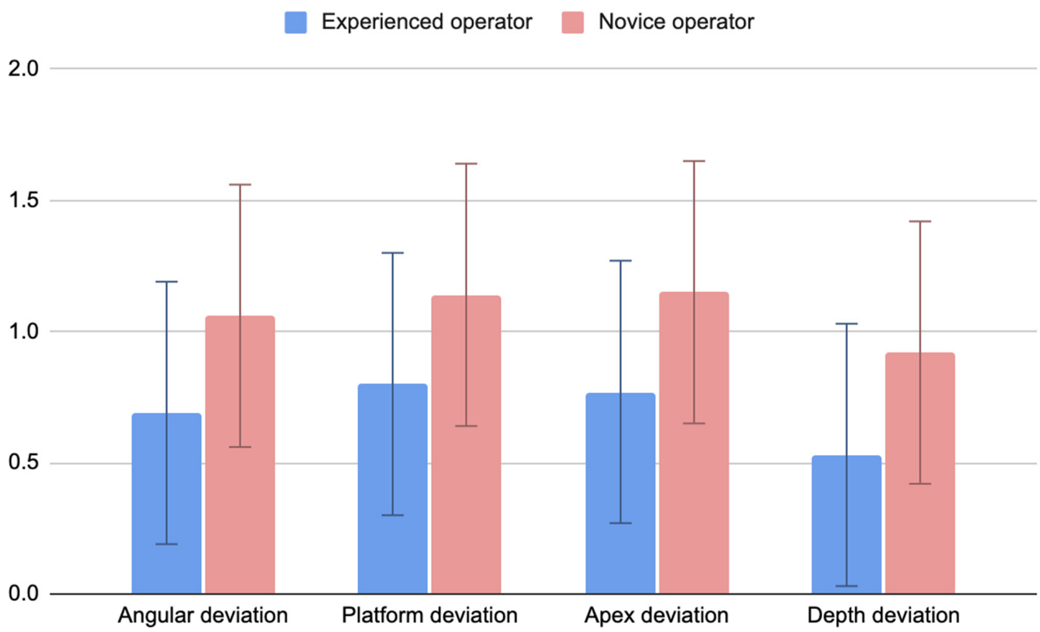

Figure 4 Bar chart demonstrates descriptive value (Mean±SD) for angular deviation, platform deviation, apex deviation and depth deviation (*p-value<0.05*)

4.2 Discussion

This study evaluated the accuracy of dental implant placement in the posterior maxilla using a dynamic computer-assisted implant surgery (dCAIS) system, comparing experienced and novice operators. Across all operators, the mean angular deviation was 0.88°, while the mean platform, apex, and depth deviations were 0.97 mm, 0.96 mm, and 0.72 mm, respectively. These findings align with the broader range of clinically acceptable deviations reported in recent systematic reviews and meta-analysis of clinical studies of dynamic navigation systems (Aghaloo et al., 2023; Pellegrino et al., 2021; Wang et al., 2022; Yu et al., 2023). The results of this study further confirm that dCAIS achieves precision comparable to sCAIS and significantly better than freehand techniques (Wei et al., 2021).

When comparing operator groups, experienced operators demonstrated lower deviations across all parameters compared to novice operators. Specifically, experienced operators achieved a mean angular deviation of 0.69°, a platform deviation of 0.80 mm, an apex deviation of 0.77 mm, and a depth deviation of 0.53 mm. In contrast, novice operators exhibited higher deviations, with a mean angular deviation of 1.06°, a platform deviation of 1.14 mm, an apex deviation of 1.15 mm, and a depth deviation of 0.92 mm. Despite these differences, statistical analysis revealed no significant differences between the two groups for any parameter ($P > 0.05$). The p-values for angular deviation ($P = 0.11$), platform deviation ($P = 0.08$), apex deviation ($P = 0.05$), and depth deviation ($P = 0.07$) indicate that the null hypothesis is accepted, suggesting that operator experience did not significantly influence implant placement accuracy when using dCAIS.

These findings are consistent with previous studies that have evaluated the impact of operator experience on accuracy when using dCAIS systems. Vercruyssen et al., (2015) reported no statistically significant differences in implant placement accuracy between experienced and novice operators using dynamic navigation systems. Sun, Lee, and Lan (2019) and Wu et al., (2020) also reported that operator experience had no impact on implant placement accuracy when using dCAIS. This suggests that the real-time feedback and guidance provided by dCAIS can effectively compensate for the lack of experience among novice operators, enabling them to achieve accuracy levels comparable to those of experienced operators.

The posterior maxilla presents unique challenges for implant placement due to its position, including a difficult access and indirect visualization (Bencharit et al., 2018), and anatomical complexity, including poor bone quality (Type III bone), sinus pneumatization, and limited residual ridge height (Xu et al., 2024). These factors often contribute to greater deviations in implant positioning compared to other regions of the jaw. Despite these challenges, the deviations observed in this study remained within clinically acceptable thresholds reported in previous research on dCAIS (Wang et al., 2022; Yu et al., 2023). This highlights the effectiveness of dCAIS in addressing anatomical difficulties specific to the posterior maxilla.

Interestingly, depth deviation was notably lower than other parameters for both groups with experienced operators achieving a mean of 0.53 mm and novice operators achieving a mean of 0.92 mm. This finding is consistent with previous studies suggesting that vertical accuracy is more precise when using guided systems (Rodrigues et al., 2023). However, angular and linear deviations (platform and apex) remain more challenging to control even with advanced navigation systems. These areas may benefit from further refinement in system design or additional operator training to improve precision.

This study highlights several limitations that should be considered in future research. First, it was conducted in vitro using maxillary models designed to simulate Type III bone quality. While these models provide a controlled environment for evaluating implant placement accuracy, they do not fully replicate real clinical conditions where factors such as patient movement, soft tissue interference, and variability in bone density could significantly affect outcomes. Second, the study involved a relatively small sample size of 30 implants placed by six operators. This limited sample size reduces the ability to apply the findings broadly to larger populations or diverse clinical scenarios. Third, the study focused exclusively on posterior maxillary implants at a single tooth position (tooth 17). Implant placement accuracy may vary depending on the anatomical site and bone quality across different regions of the jaw which were not explored in this study. Additionally, future studies should expand to include larger sample sizes and be conducted in clinical settings with real patients to better reflect practical conditions. Incorporating a wider range of anatomical sites and bone qualities would also provide a more comprehensive understanding of how these factors influence implant placement accuracy.

5. Conclusion

Dynamic computer-assisted implant surgery (dCAIS) systems, such as X-Guide, have proven to be effective tools for achieving accurate implant placement in the posterior maxilla, regardless of operator experience. As a result, both experienced and novice operators achieved clinically acceptable results across all evaluated parameters, suggesting that dCAIS minimizes the influence of operator skills by providing real-time guidance during surgery. Future research should focus on validating these results in clinical settings with larger sample sizes and exploring long-term clinical implications of using dynamic navigation systems.

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