Comparison of Implant Accuracy between Experienced and Inexperienced Operator using Dynamic Computer-assisted Implant Surgery in Esthetic Zone: in Vitro Study

Jirasita Na Songkla[1], Pravej Serichetaphongse[2, 3], and Wareeratn Chengprapakorn[4,*]

[1]Esthetic Restorative and implant Dentistry, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand
[2]School of Dentistry, Siam University, Bangkok, Thailand
[3]Dental Center, Bumrungrad International Hospital, Bangkok, Thailand
[4]Department of Prosthodontics, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand
[*]Corresponding author, E-mail: jirasita.m@gmail.com

Abstract

In this study, the accuracy of implant placement by experienced versus inexperienced operators was evaluated within the esthetic region, utilizing dynamic computer-assisted surgery (d-CAIS) systems. A total of 30 implants were installed by 3 experienced and 3 inexperienced operators using d-CAIS (X-guide, Nobel Biocare) in a partial edentulous maxillary resin model. Implants from Neodent (Helix GM) systems were utilized. Post-operative CBCT scan were analyzed for positional accuracy using coDiagnostiX software, focusing on four parameters: A space in front of angle(degree), 3D platform(mm), 3D apex(mm), and depth deviation(mm). Statistical analyses were performed using SPSS. An independent t-test was used to compare the deviation between two operator groups ($p<0.05$). The results showed no significant difference between the two groups of operators in terms of angular deviation and 3D platform deviation. However, 3D apex deviation of inexperienced operators was significantly higher than in the experienced group (0.82 ± 0.25 vs 1.04 ± 0.25, $p=0.021$). Moreover, inexperienced group also provided significantly higher depth deviation than experienced operators. (0.44 ± 0.35 vs 0.83 ± 0.36, $p=0.005$). Thus, it can be concluded that d-CAIS assists inexperienced operators achieving implant accuracy results in terms of angle and 3D entry similar to those of experienced operators.

Keywords: *dental implant, dynamic computer-assisted surgery, accuracy, inexperienced operator, experienced operator*

1. Introduction

Dental implants are widely regarded as a highly successful and common method for tooth replacement, particularly in the anterior region, where both function and aesthetics are crucial considerations. Achieving optimal outcomes with dental implants relies strongly on the precise 3D prosthetic-driven implant positioning (Buser et al., 2004). However, many studies have shown that implant placement using a freehand technique often fails to accurately replicate the planned position (Siqueira et al., 2020). A previous study suggested that freehand placement can result in angular deviations of up to 10 degrees (Wei, et al., 2021). For instance, the advent of digital workflows, including static and dynamic computer-assisted implant surgery (CAIS), has significantly improved the accuracy of implant placement (Tahmaseb et al., 2018).

Dynamic CAIS has been shown to improve the success rate of implant placement when compared to traditional freehand techniques (Pellegrino et al., 2020; Tao, et al., 2024). Systematic reviews and meta-analyses reported that dynamic CAIS reduces implant placement deviation, particularly angular deviation, by approximately 3 to 5 degrees, making it a more precise method (Schnutenhaus et al., 2021). This technology allows for the virtual planning of implants in their optimal 3D position, with real-time tracking during surgery (Battista et al., 2022). However, while d-CAIS offers enhanced accuracy, it does not control the surgeon's hand movements. As a result, the skill of the operator, including hand-eye coordination, remains a critical factor in determining the final implant position (Sun et al., 2019). Therefore, authors believed that the experience and expertise of the surgeon play an essential role in achieving placement accuracy.

Although many studies have compared the accuracy of implant placement between the freehand protocol and d-CAIS and confirmed that d-CAIS can assist surgeons to achieve greater accuracy than the freehand protocol, the studies are only limited to experienced operators. Nowadays, only a few studies have explored the influence of the experience level of the operator on implant placement accuracy outcome when using d-CAIS. Thus, the aim of this study is to investigate whether dynamic CAIS can help inexperienced operators achieve similar placement accuracy as their more experienced counterparts in the anterior region. The null hypothesis of this study was that there is no difference in implant placement deviation between experienced and inexperienced operators when using d-CAIS.

2. Objectives

The objectives of the study were to compare the implant planned and actual placed position deviation between experienced and inexperienced operators in 4 parameters:

1) Angular deviation (degree) which is expressed in degrees was calculated as the 3D angle between the longitudinal axis of the planned and placed implant

2) 3D Platform deviation (mm) which is defined as the 3D distance between the platform centre of the planned and placed implants

3) 3D Apex deviation (mm) which is defined as the 3D distance between the apical centre of the planned and placed implants.

4) Depth deviation (mm) which is defined as the 2D distance measured vertically between the platform centre of the planned and placed implants

3. Materials and Methods

This study was approved by the Ethics Committee at the Faculty of Dentistry, Chulalongkorn University (HREC-DCU 2023-098) and was registered at the Thai Clinical Trials Registry (TCTR20240504005). Sample size calculation was performed using GPower software based on a pilot study, resulting in 30 implant samples divided into 2 groups, with 15 Neodent implants (Helix GM, 4.3 mm diameter, 11.5 mm length) per group. A total of 6 participants performed 5 implant placements each.

Participants included three experienced surgeons and three inexperienced space. The criteria used to recruit operators were working experience in the implantology field (year) and number of implant surgeries in patients. Experienced operators were defined as surgeons who had more than 5 years of experience and 100 implants surgery performed, while inexperienced operators were surgeons who had less than 5 years of experience and performed fewer than 10 implants surgeries. None of them had prior experience with dynamic computer-assisted implant surgery (dCAIS).

Figure 1 Maxillary resin model with central incisor healed edentulous area

Drillable resin models representing type II bone quality (Zarb, & Zarb, 1985),with missing upper left central incisor (#21) were used for simulation (Figure1). Implant position planning involved a cone beam computed tomography (CBCT) scan (Dentsply Sirona, Germany) with fiducial markers, followed by 3D intraoral surface scanning (3Shape Trios, Denmark). The DICOM and STL files were merged and analyzed using 3D planning software (3Shape Trios), with the implant positioned according to the planned restoration (Figure 2).

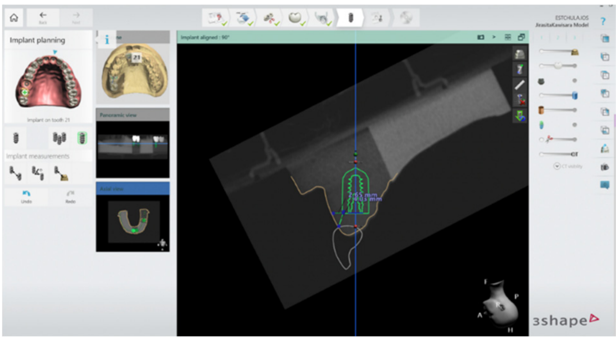

Figure 2 Implant-planning with Implant studio software
(Implant Studio version 2019.1.5, 3Shape, Copenhagen, Denmark)

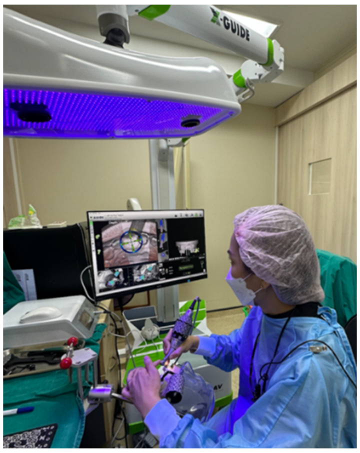

Figure 3 The operation of implant placement using X-guide and the position of the model mounted to the phantom head.

The implant platform was set 3 mm apically to the CEJ and 1.5 mm palatally from the labial wall. Then, implant placement surgical simulations by 6 operators were conducted on dental phantom heads with resin models (Figure 3). Following surgery, 30 implants underwent CBCT scanning, and post-operative DICOM files were superimposed with pre-operative virtual planning using coDiagnostiX software to assess implant position deviations (Figure 4). Deviations were analyzed in 4 parameters including angular, 3D entry, 3D apex, and depth, as mentioned in objectives (Figure 5).

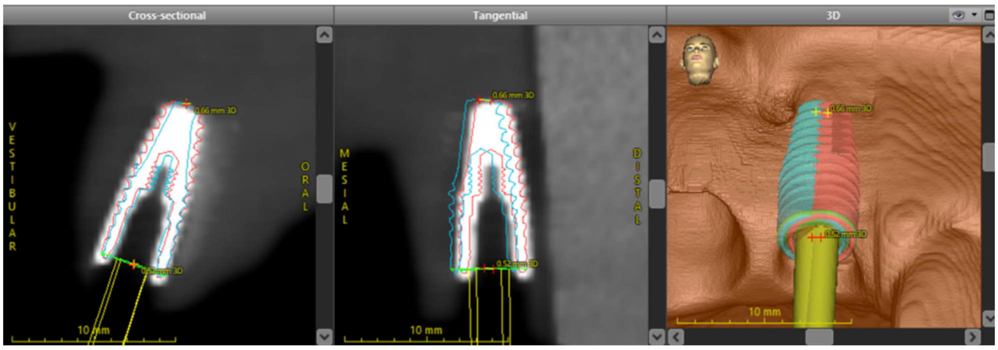

Figure 4 Treatment evaluation of implant placement. the blue figure represented the planned position of implant, while the red figure represented the actual placed position of the implant

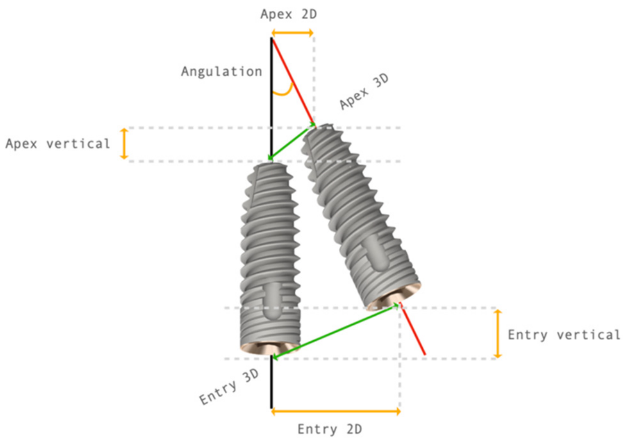

Figure 5 Illustration of parameters to analyze the accuracy of planned and placed implant placement, including angle deviation, 3D platform deviation, 3D apex deviation and depth deviation.

Statistical analysis was performed using SPSS software. Descriptive data were presented as means ± standard deviation. An independent t-test was used to compare the deviation between two operator groups. Statistical significance was set at $p < 0.05$.

4. Results and Discussion

4.1 Results

The total of 30 implant placement positions were analyzed (p<0.05). Total average angular (degree), 3D platform (mm), 3D apex (mm) and depth deviation (mm) of all 6 operators were 1.87 ± 0.63, 0.95 ± 0.20, 0.93 ± 0.27 and 0.63 ± 0.40, respectively. Three GM Helix implants that were placed by inexperienced operators suffered from incomplete insertion in the apico-coronal dimension, with maximum depth deviation at 1.35 mm. When comparing between two group of operators, overall deviation of inexperienced operators was higher than experienced operator group. Nevertheless, no significant difference was found between the two groups of operators in terms of angular deviation and 3D platform deviation. The result of the position analysis revealed that the 3D apex deviation of inexperienced operators was significantly higher than that of the experienced group (0.82 ± 0.25 vs 1.04 ± 0.25, p=0.021). Moreover, inexperienced group also provided significantly higher depth deviation than experienced operators. (0.44 ± 0.35 vs 0.83 ± 0.36, p=0.005), see Table 1.

Table 1 Descriptive values (Mean ± SD) categorized by experience of the operator

Operator	Deviation							
	Angular (°)	*p*-value	3D Platform (mm)	*p*-value	3D Apex (mm)	*p*-value	Depth (mm)	*p*-value
Experienced (N=15)	1.79 ± 0.55	(0.516)	0.89 ± 0.24	(0.074)	0.82 ± 0.25	**(0.021)**	0.44 ± 0.35	**(0.005)**
Inexperienced (N=15)	1.95 ± 0.71		1.02 ± 0.12		1.04 ± 0.25		0.83 ± 0.36	
Total (N=30)	1.87 ± 0.63		0.95 ± 0.20		0.93 ± 0.27		0.63 ± 0.40	

4.2 Discussion

The results of this surgical model experiment indicate that the level of experience of the operator did not influence the implant placement accuracy outcome in terms of angular and 3D platform deviation when using d-CAIS. However, depth and apex deviation performed by inexperienced operators were significantly higher than that of the experienced group, as mentioned in Table1, indicating that the level of experience had an influence on 3D apex and depth deviation**.** So, the null hypothesis of this study was rejected.

This comparable precision of implant placement between two groups of operators in terms of angular and 3D platform can be attributed to the real-time capabilities of d-CAIS, which allows continuous monitoring of the angle and entry point of the instrument during the osteotomy sequence and implant insertion. Furthermore, the system tracks adjustments to the orientation of the surgical instruments, ensuring that the final implant position is accurately achieved. Overall, the deviation values observed in this study align with those reported in previous research (Aydemir, & Arısan, 2020; Jaemsuwan et al., 2023; Pimkhaokham et al., 2023; Spille et al., 2022). Specifically, the total angular deviation was 1.87 ± 0.63 degrees, which is less than previous findings from a meta-analysis that showed d-CAIS significantly improves angular accuracy compared to freehand placement, which typically has an angular deviation of 3.5 degrees (Wei et al., 2021). Thus, the outcome of this experiment implied that d-CAIS enables less experienced operators to achieve comparable accuracy to that of experienced surgeons in terms of angular and 3D platforms.

On the other hand, the result pointed out that the level of experience had an influence on the depth and apex deviation outcome. It was noted in this study that some of the samples from the inexperienced operator group have suffered from incomplete insertion due to insufficient implant site preparation in depth, which provides extremely high depth deviation in this group. A potential explanation for this discrepancy could be related to the level of expertise and hand motor skill of the operator. We observed from the experiment that although d-CAIS provides 3D guidance for implant drills, the proper preparation of the implant site, including ensuring adequate width and depth, remains under the operator's control and hand motor skill. As highlighted by previous research, d-CAIS does not regulate the surgeon's hand movements. Moreover, the learning curve for precise implant placement is steep, and more experienced operators tend to produce more accurate results, particularly when using complex systems like dynamic computer-assisted implant surgery (CAIS) (Cassetta, & Bellardini, 2017; Ma et al., 2023; Sun et al., 2019), which operators must simultaneously monitor the real-time position of the drill on the screen and the actual surgical site, suggesting that the operator need a learning curve (Wang et al., 2023). Thus, prior training with the d-CAIS system is important, especially for less experienced operators (Block et al., 2017). Additionally, careful case selection for inexperienced operators is crucial to prevent complications from potential apical and depth deviations in implant placement.

Despite the benefit achieved from this study, some limitations were found from this experiment. Besides, the outcomes of this in vitro investigation might not completely simulate the clinical practice in dental implant placement via d-CAIS because of the limited sample size. Moreover, the influence of real-life variables may result in more deviations in implant positioning. To reach more benefit from implant placement via d-CAIS, future clinical studies should be designed to assess whether the experience of the operator and implant design have an influence on implant accuracy and primary stability.

5. Conclusion

Within the limitations of this study, it can be concluded that level of experience had an influence on implant placement accuracy in terms of 3D apex and 3D depth.

6. Acknowledgements

The author would like to acknowledge to Associate Professor Dr. Soranun Chantarangsu for her assistance with statistical analysis, which was instrumental in refining the research findings.

7. References

Aydemir, C. A., & Arısan, V. (2020). Accuracy of dental implant placement via dynamic navigation or the freehand method: A split-mouth randomized controlled clinical trial. *Clinical Oral Implants Research*, *31*(3), 255-263. https://doi.org/10.1111/clr.13563

Battista, E., Gasparro, R., Cacciola, M., Sammartino, G., & Marenzi, G. (2022). Dynamic Navigation System for Immediate Implant Placement in the Maxillary Aesthetic Region. *Applied Sciences, 12*(11), 5510. Retrieved from https://www.mdpi.com/2076-3417/12/11/5510

Block, M. S., Emery, R. W., Lank, K., & Ryan, J. (2017). Implant Placement Accuracy Using Dynamic Navigation. *International Journal of Oral & Maxillofacial Implants*, *32*(1), 92-99. https://doi.org/10.11607/jomi.5004

Buser, D., Martin, W., & Belser, U. C. (2004). Optimizing esthetics for implant restorations in the anterior maxilla: anatomic and surgical considerations. *International Journal of Oral & Maxillofacial Implants*, *19*(7), 43-61.

Cassetta, M., & Bellardini, M. (2017). How much does experience in guided implant surgery play a role in accuracy? A randomized controlled pilot study. *International Journal of Oral and Maxillofacial Surgery*, *46 7*, 922-930.

Jaemsuwan, S., Arunjaroensuk, S., Kaboosaya, B., Subbalekha, K., Mattheos, N., & Pimkhaokham, A. (2023). Comparison of the accuracy of implant position among freehand implant placement, static and dynamic computer-assisted implant surgery in fully edentulous patients: a non-randomized prospective study. *International Journal of Oral and Maxillofacial Surgery*, *52*(2), 264-271. https://doi.org/10.1016/j.ijom.2022.05.009

Ma, L., Ye, M., Wu, M., Chen, X., & Shen, S. (2023). A retrospective study of dynamic navigation system-assisted implant placement. *BMC Oral Health, 23*(1), 759. https://doi.org/10.1186/s12903-023-03481-2

Pellegrino, G., Bellini, P., Cavallini, P. F., Ferri, A., Zacchino, A., Taraschi, V., . . . Consolo, U. (2020). Dynamic Navigation in Dental Implantology: The Influence of Surgical Experience on Implant Placement Accuracy and Operating Time. An in Vitro Study. *International Journal of Environmental Research and Public Health*, *17*(6). https://doi.org/10.3390/ijerph17062153

Pimkhaokham, A., Chow, J., Pozzi, A., Arunjaroensuk, S., Subbalehka, K., & Mattheos, N. (2023). Computer-assisted and robotic implant surgery: Assessing the outcome measures of accuracy and educational implications. *Clinical Oral Implants Research*, *35*(8), *939-953*. https://doi.org/10.1111/clr.14213

Schnutenhaus, S., Edelmann, C., Knipper, A., & Luthardt, R. G. (2021). Accuracy of Dynamic Computer-Assisted Implant Placement: A Systematic Review and Meta-Analysis of Clinical and In Vitro Studies. *Journal of Clinical Medicine, 10*(4), 704. Retrieved from https://www.mdpi.com/2077-0383/10/4/704

Siqueira, R., Chen, Z., Galli, M., Saleh, I., Wang, H. L., & Chan, H. L. (2020). Does a fully digital workflow improve the accuracy of computer-assisted implant surgery in partially edentulous patients? A systematic review of clinical trials. *Clinical Implant Dentistry and Related Research, 22*(6), 660-671. https://doi.org/10.1111/cid.12937

Sittikornpaiboon, P., Arunjaroensuk, S., Kaboosaya, B., Subbalekha, K., Mattheos, N., & Pimkhaokham, A. (2021). Comparison of the accuracy of implant placement using different drilling systems for static computer-assisted implant surgery: A simulation-based experimental study. *Clinical Implant Dentistry and Related Research*, *23*(4), 635-643. https://doi.org/10.1111/cid.13032

Spille, J., Helmstetter, E., Kübel, P., Weitkamp, J. T., Wagner, J., Wieker, H., . . . Gülses, A. (2022). Learning Curve and Comparison of Dynamic Implant Placement Accuracy Using a Navigation System in Young Professionals. *Dentistry Journal (Basel)*, *10*(10), 187. https://doi.org/10.3390/dj10100187

Sun, T. M., Lee, H. E., & Lan, T. H. (2019). The influence of dental experience on a dental implant navigation system. *BMC Oral Health, 19*(1), 222. https://doi.org/10.1186/s12903-019-0914-2

Tahmaseb, A., Wu, V., Wismeijer, D., Coucke, W., & Evans, C. (2018). The accuracy of static computer-aided implant surgery: A systematic review and meta-analysis. *Clinical Oral Implants Research, 29*(16), 416-435. https://doi.org/10.1111/clr.13346

Tao, B., Wang, N., Ling, X., Ye, L., & Wu, Y. (2024). Comparison of the accuracy of dynamic navigation and the free hand approaches in the placement of pterygoid implants in the completely edentulous maxilla: An in vitro study. *Journal of Dental Sciences*, *19*(4), 2341-2347. https://doi.org/10.1016/j.jds.2024.01.024

Wang, W., Zhuang, M., Li, S., Shen, Y., Lan, R., Wu, Y., & Wang, F. (2023). Exploring training dental implant placement using static or dynamic devices among dental students. *European Journal of Dental Education*, *27*(3), 438-448. https://doi.org/10.1111/eje.12825

Wei, S. M., Zhu, Y., Wei, J. X., Zhang, C. N., Shi, J. Y., & Lai, H. C. (2021). Accuracy of dynamic navigation in implant surgery: A systematic review and meta-analysis. *Clinical Oral Implants Research*, *32*(4), 383-393. https://doi.org/10.1111/clr.13719

Zarb, G. A., & Zarb, F. L. (1985). Tissue integrated dental prostheses. *Quintessence International*, *16*(1), 39-42.