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Original Article

Training outcomes of novice clinicians in the use of dynamic computer assisted implant surgery: A prospective comparative study

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KEYWORDS
Dynamic computer assisted implant surgery (d-CAIS);
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Abstract *Background/Purpose:* The increasing importance of computer assisted implant surgery (CAIS) in the practice of implant dentistry calls for adequate education and training of clinicians. However, limited evidence exists to support optimal educational strategies and best practices. This study aimed to investigate the effectiveness of distributed training with dynamic CAIS (d-CAIS) on the precision of freehand implant placement by inexperienced operators.
Materials and methods: Six senior undergraduate dental students underwent simulation training in freehand implant surgery (5 implants) followed by distributed training in d-CAIS (6 implants). A final assessment of freehand implant placement (5 implants) was conducted thereafter. Outcomes were compared to a benchmark set by an experienced surgeon who repeated the same simulation exercises. Total surgical time and implant placement precision were recorded.
Results: The average precision of implant placement improved significantly after the d-CAIS training for novice operators. 3D platform deviation (1.63 ± 0.85 vs 0.92 ± 0.23; $P < 0.001$), 3D apical deviation (1.93 ± 0.88 vs 1.21 ± 0.19; $P < 0.001$), and angular deviation (5.27 ± 2.30 vs 2.74 ± 1.37; $P < 0.001$). The students achieved platform deviation comparable to this of the expert, but lagged in angle, apex precision, and total surgical time.

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Conclusion: Short-term, distributed simulation training with d-CAIS can significantly enhance the precision of freehand implant placement by novice operators. However, novice operators still lagged at certain aspects of precision and surgical time when compared with the performance of an experienced surgeon in the same setup.

Introduction

Computer assisted implant surgery (CAIS) involves at present a well-established array of protocols and technologies aiming to facilitate the precise placement of dental implants, as based on digital 3-dimensional pre-surgical planning. The CAIS currently encompasses two main technological protocols, static (s-CAIS), employing a 3D printed surgical guide, and dynamic (d-CAIS), utilizing real-time navigation technology. Either s-CAIS or d-CAIS, are well documented to significantly increase accuracy of implant placement, as compared to freehand implant surgery,[1,2] while also reducing invasiveness and empowering immediacy protocols.[3] In addition, with the emerging paradigm of implant dentistry focused in achieving the optimal prosthetic design for long term success and health of the peri-implant tissue,[4,5] CAIS has become a critical step of the digital workflow, allowing the transfer of the optimal pre-surgical design to the patients' anatomy.

The increasing importance of CAIS in the practice of implant dentistry calls for adequate education and training of clinicians in the respective technologies and methods.[6] However, as CAIS includes many diverse technologies and protocols, its implementation in the education of implant surgeons remains challenging, while little evidence is available to support educational strategies and best practice. Clinical and simulation studies have suggested a significant "learning curve" effect for both the operating time and accuracy of placement when either novice or experienced implant surgeons are trained in the use of d-CAIS.[7—13] Studies with endoscopic and robotic surgery have suggested that certain cognitive skills such as Spatial Representation Ability are essential for effective use of such technologies by the surgeon, while valuable in conventional surgery as well. Others have also suggested that the use of d-CAIS could have an additional educational value, supporting novice operators to develop essential surgical competences which could then be equally applied to computer assisted or conventional surgery.[6,9] The pathway of novice clinicians to competent use of d-CAIS has not been fully investigated. Few simulation studies suggest that inexperienced operators can reach outcomes similar to these of experienced ones after structured training,[10,11] while distributed sessions over a longer period of time appear to be more effective.[13] At the same time, most of such studies are based on postgraduate students and clinicians with prior experience with implant dentistry.

The aim of this study was to investigate the effectiveness of distributed training with d-CAIS in the precision of freehand implant placement by inexperienced operators. Furthermore, the study aimed to compare the precision achieved by inexperienced operators with this of an expert at the identical tasks and settings. The primary outcome investigated was precision of implant placement (reproducibility) as expressed by deviation at platform, apex and angle, while secondary outcome was the total time of the simulated surgical procedure.

Materials and methods

The institutional review board has waived the requirement for approval for this simulation study, which was registered in Thai Clinical Trials Registry (TCTR ID: TCTR20230608005).

Sample size calculation

The sample size was determined using statistical software (G*power 3.1, Version 3.1.9.6, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany), based on a two-dependent t-test with a 0.01 Type I error and 0.95 power. The angulation deviation values before and after training via d-CAIS (5.288 ± 2.653 vs 2.898 ± 1.474) from the previous study were utilized for the calculation.[9] The minimum required sample size was 20. Considering there were 6 operators, $20/6 = 4$ implants were necessary for each operator. Incorporating a 20% compensation factor, each operator was tasked with five attempts both before and after training.

Experienced and novice operators

One experienced dental implant surgeon and six senior dental students were enrolled in the study. The experienced operator was a specialist with over 20 years of experience in implant surgery and also highly experienced with d-CAIS. The senior (6th year) dental students had no prior clinical experience with implant surgery, neither were they familiar with dynamic-CAIS. All senior dental students had received theoretical education on surgical and restorative aspects of implant dentistry at this point in their studies. Additionally, all operators were in good health and had no vision problems. After enrollment in the study they received a short practical training module with the following components:

(1) Importance of restorative-driven implant dentistry and principles of optimal implant position.

(2) Freehand surgical implant placement protocol with Straumann BLT dental implant (Institut Straumann AG, Basel, Switzerland).
(3) Theoretical introduction and orientation on the dynamic CAIS navigation device and function.

Simulation exercise

One hundred and seven custom polyurethane upper arch models were prepared with missing tooth 11, created from 3D models of an actual patient's anatomy. The mean density of the edentulous area block in the anterior maxilla was 0.55 g/cm^3 simulating a D3 type of bone.[14]

The radiopaque model was scanned with cone beam computed tomography (CBCT) (i-CAT machine, Imaging Science International LLC. Hatfield, PA, USA) with a voxel resolution of 0.3 with four radiopaque fiducial markers on an occlusal guide device (Iris-100, EPED Inc., Hsinchu, Taiwan) which positioned on the teeth of the maxillary model. Consequently the DICOM data set from the CBCT was uploaded to the dynamic navigation system (Iris-100, EPED Inc.). Finally, the optimal 3D position of the implant was planned by one expert in the software of the dynamic navigation system (Iris-100, EPED Inc.).

Simulated surgical procedures

All participants performed implant placement on maxillary right central incisor using 4.1 mm diameter and 10 mm length, Straumann BLT implant (Institut Straumann AG), according to manufacturer's recommended procedure. As baseline training, the novice participants placed 5 implants consecutively with freehand surgery. After a break of 7 days the d-CAIS simulation training was initiated, consisting of the placement of 6 implants distributed over 5 days, with each day of training followed by a day of break (Fig. 1). Another 7 days after the d-CAIS simulation training, novice participants conducted a final simulation exercise with the placement of 5 implants with freehand surgery. The experienced surgeon used the same setup with d-CAIS for the placement of 6 implants, while 7 days later he placed another 5 implants with free hand surgery.

Outcomes measures and statistical analysis

Precision of implant placement was defined as the primary outcome of this study and it was assessed by means of measuring 3D deviation of placed from planned implant position at centre of implant platform (mm), implant apex (mm), and angle (degrees). As secondary outcome, the total surgical time of each implant placement was assessed. All measurements were inserted into a spreadsheet and analysed by means of IBM SPSS Statistics software (version 22 software SPSS Inc., Chicago, IL, USA). Mean difference between planned and actual position were compared for each operator using pair t-test and Wilcoxon Signed Ranks Test. The Independent Samples Test was used to assess significant differences of deviation and surgical time between the group of novice operators and the experienced surgeon. *P*-value of 0.05 was considered the level of statistical significance.

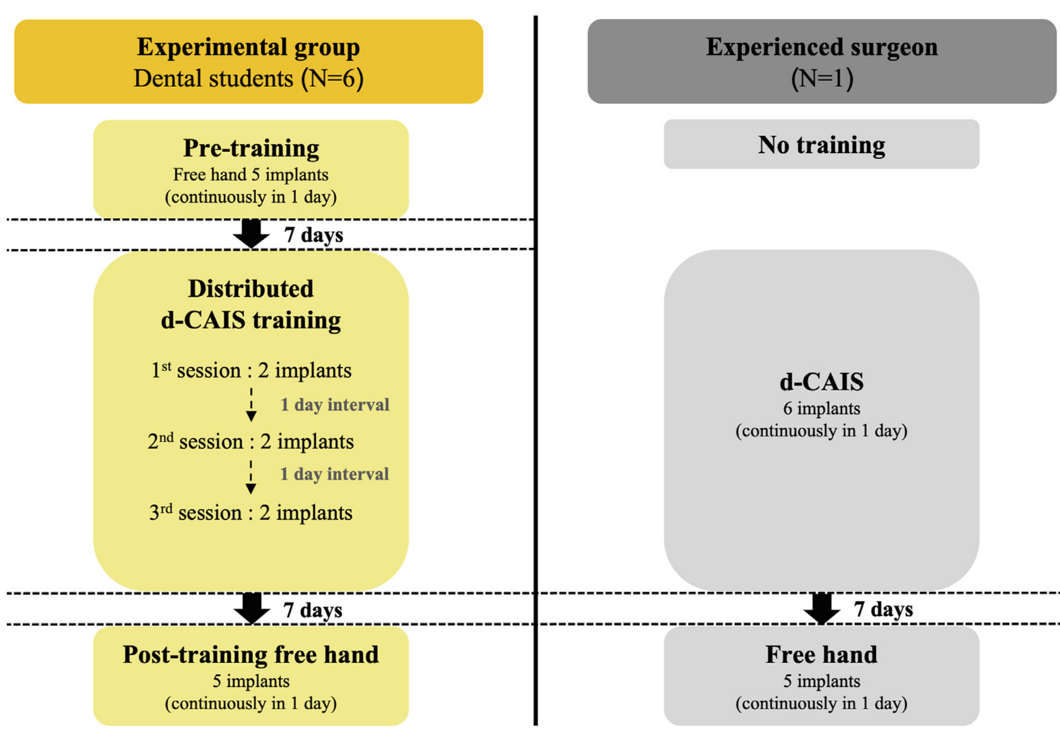

Figure 1 Flowchart of the study with the main training and assessment events for the dental students (novice, orange) and the corresponding tests for the experienced surgeon (grey). Abbreviation: d-CAIS: dynamic computer-assisted implant surgery. (For interpretation of the references to colour/colour in this figure legend, the reader is referred to the Web version of this article.)

Results

One hunder and seven implant placements were conducted and recorded as planned. All operators were right handed.

The average precision of implant placement by the novice operators improved significantly between baseline and post d-CAIS simulation training: 3D platform deviation (1.63 ± 0.85 vs 0.92 ± 0.23; $P < 0.001$), 3D apical deviation (1.93 ± 0.88 vs 1.21 ± 0.19; $P < 0.001$), and angular deviation (5.27 ± 2.30 vs 2.74 ± 1.37; $P < 0.001$) (Table 1). The difference in the average precision of freehand implant placement between the experienced operator and the novice post d-CAIS training was not significant for the 3D platform deviation (0.73 ± 0.21 vs 0.92 ± 0.23; $P = 0.95$), it was however significant in the apical (0.82 ± 0.23 vs 1.21 ± 0.19; $P < 0.001$) and angular deviation (1.84 ± 0.39 vs 2.74 ± 1.37; $P = 0.007$) (Table 2).

Likewise, the difference in the average precision of implants placed with d-CAIS by the experienced surgeon and the novice operators was not significant for 3D platform deviation (0.71 ± 0.20 vs 0.89 ± 0.27; $P = 0.126$), but was for 3D apical (0.67 ± 0.26 vs 1.13 ± 0.37; $P = 0.005$), and angular deviation (1.42 ± 1.19 vs 2.49 ± 0.96; $P = 0.018$) (Table 3).

The average surgical time of freehand surgeries was significantly reduced between pre- and post d-CAIS training (534.27 ± 58.05 vs 358.53 ± 35.05; $P < 0.001$). However, novice operators took significantly longer time than the experienced surgeon with both freehand and dynamic-CAIS surgery.

Discussion

The main aim of this simulation study was to document the progress of inexperienced operators when trained in the use of d-CAIS and whether the skills acquired during this training can be transferred to freehand implant placement. Furthermore, the study aimed to compare the progress of novice operators to the benchmark of an expert with regards to both the d-CAIS as well as the freehand placement.

Acquisition of basic surgical competence, as well as progression to higher levels of efficiency and complexity is a complex process that is often described as a "learning curve". The term was originally introduced as a true curve depicting the relationship between the time on task or amount of practice and the level of performance and is widely applied in the training of computer assisted and robotic surgical competences.[15–17] Understanding the learning curve of a surgeon with a new technology allows educators to define important benchmarks such as the level of essential skills for safe practice, and the level associated with mastery of the technique.[17] Commonly applied concepts of the learning curve identify four different types, with the diminishing-returns and the increasing-returns curves being the most representative.[6]

Clinical and simulation studies with novice and experienced operators have suggested the presence of an "increasing-returns" learning curve in the training with d-CAIS, something that has not been found in the training of s-CAIS.[7,9,12,18,19] The increasing-returns curve often

Table 1 Deviation and surgical time with free-hand implant placement at pre and post training stage with novice participants.

Parameters	Pre-training	Post-training	*P*-value (0.05)
3D platform deviation (mm)	1.63 ± 0.85	0.92 ± 0.23	<0.001*
3D apical deviation (mm)	1.93 ± 0.88	1.21 ± 0.19	<0.001*
Angular deviation (degree)	5.27 ± 2.30	2.74 ± 1.37	<0.001*
Time (s)	534.27 ± 58.05	358.53 ± 35.05	<0.001*

*Statistical significance at $P < 0.05$.
a. Deviation measured at the platform level in three dimensions, b. Deviation measured at the apical level in three dimensions, c. Angular deviation measured in degrees, d. Total surgical time measured in seconds.
Abbreviations: 3D: Three-dimensional; mm: millimeters; s: seconds.

Table 2 Deviation and surgical time of novice participants and experienced surgeon with freehand implant surgery.

Parameters	Groups	Post-training	*P*-value (0.05)
3D platform deviation (mm)	Novice participants	0.92 ± 0.23	0.950
	Experienced surgeon	0.73 ± 0.21	
3D apical deviation (mm)	Novice participants	1.21 ± 0.19	<0.001*
	Experienced surgeon	0.82 ± 0.23	
Angular deviation (degree)	Novice participants	2.74 ± 1.37	0.007*
	Experienced surgeon	1.84 ± 0.39	
Time (s)	Novice participants	358.53 ± 35.05	<0.001*
	Experienced surgeon	153.80 ± 19.72	

*Statistical significance at $P < 0.05$.
a. Deviation measured at the platform level in three dimensions, b. Deviation measured at the apical level in three dimensions, c. Angular deviation measured in degrees, d. Total surgical time measured in seconds.
Abbreviations: 3D: Three-dimensional; mm: millimeters; s: seconds.

Table 3 Deviation and surgical time of novice participants and experienced surgeon using dynamic computer assisted implant surgery (d-CAIS).

Parameters	Groups	d-CAIS	*P*-value (0.05)
3D platform deviation (mm)	Novice participants	0.89 ± 0.27	0.126
	Experienced surgeon	0.71 ± 0.20	
3D apical deviation (mm)	Novice participants	1.13 ± 0.37	0.005*
	Experienced surgeon	0.67 ± 0.26	
Angular deviation (degree)	Novice participants	2.49 ± 0.96	0.018*
	Experienced surgeon	1.42 ± 1.19	
Time (s)	Novice participants	605.25 ± 85.88	<0.001*
	Experienced surgeon	319.00 ± 25.58	

*Statistical significance at $P < 0.05$.

a. Deviation measured at the platform level in three dimensions, b. Deviation measured at the apical level in three dimensions, c. Angular deviation measured in degrees, d. Total surgical time measured in seconds.

Abbreviations: 3D: Three-dimensional; mm: millimeters; s: seconds.

described as "steep" is characteristic of a task where the rate of progression is slow at the beginning but rises with practice until full proficiency is obtained. Such tasks might be taught more efficiently through multiple repeated sessions distributed over longer periods of time, rather than concentrated one-off educational events.[13] The results of this small scale simulation study, appear well in accordance with these observations of an increasing-returns learning curve. Dynamic CAIS is in essence a freehand surgery with real time visual guidance, where the operator needs to continuously synthesise the spatial understanding of the surgical field with the feedback from a 2D computer screen. Although this setup can support better surgical outcomes, the combined tasks might pose a higher cognitive challenge to the surgeon who now has to act on the basis of two constant information flows. At the basis of successful interpretation of screen feedback lies an important cognitive ability called Spatial Representation (SR), a competence which relates to the interpretation of 2-dimensional representations (radiographs, images, screens) into 3-dimensional spatial understanding of anatomic structures.[20] Studies on robotic and endoscopic surgery have documented the importance of SR,[17,21] as well the fact that as all skills, this cognitive function can improve by targeted educational interventions. Consequently, the skillset and competences required by the surgeon practicing dynamic CAIS might be more complex than those required by freehand surgery and different to these of static CAIS. However, as the results of this study suggest, skills acquired through distributed training in implant placement with d-CAIS could help the operator maintain high precision even when later implants are placed freehand.

Surgeon's level of experience is often reported to be a critical factor influencing clinical outcomes.[22] In particular when the surgical procedures involve a new technology, surgeon's experience can be multifold: experience with the procedure and the specific anatomic region, but also experience with the respective technology. Simulation studies with d-CAIS have shown no difference in terms of accuracy when CAIS was used by experienced and novice surgeons.[10,11] However, the novice operators in these studies were already qualified implant surgeons, experienced with implant placement but inexperienced with the d-CAIS. The novice surgeons in the present study were undergraduate students, without any clinical experience with implant placement, while the expert benchmark was of a surgeon with extended experience in both implant surgery and d-CAIS. Interestingly, novice surgeons of that level could reach some elements but not the complete level of precision reached by the expert surgeon. Although the deviation at platform level was comparable, the deviation at apex and angle remained significantly higher than these of the expert. It should be noted that angular deviation and deviation at apex are not independent variables, but rather interconnected, with the increase in the angular deviation leading to corresponding increase in the apical deviation, amplified by the implant length. Thus, the clinical experience of the operator should be considered critical for improving all parametres of precision, also reflected in the present study. It might be not surprising that novice operators are better at reaching precision at the platform level, where direct visual inspection and reference points from the neighbouring bone and anatomic structures are available. On the contrary, control of the angle might require much more experience, as subtle deviations are not directly visible. Allowing a better control of the implant placement angle might be one of the comparative strengths of dynamic as opposes to static CAIS, as suggested in a randomized clinical trial,[23] but also supported by two meta-analyses.[2,24]

The primary outcome investigated in this study was precision, as described by 3-dimensional and angular deviation. Studies assessing the effectiveness of CAIS have typically reported "accuracy" of implant position, yet accuracy of an experimental procedure is defined as the combination of its trueness and precision (ISO 5725−1). In the case of implant surgery, trueness can be assessed in clinical conditions by measuring how close the implant position is to the initially planned one, but precision is a measure of the repeatability or reproducibility of the outcomes and can only be assessed in simulation studies.

The results of this study should be interpreted under the limitations of the study. The study included a small sample of students and the outcomes of the students trained with d-CAIS were compared only to benchmark outcomes of the expert, without a control group. Thus, the improvement observed could not be solely attributed to the impact of d-CAIS, but it is possible that the repetitive training in itself had contributed to the results. Furthermore, the interventions studied spread in a relatively short period of time. The anatomic position chosen for the simulation exercise might have also had certain influence on the results. In the future, studies with larger sample, proper control groups and longer duration would help to better understand the observations of this study and also support the design of effective educational interventions for novice operators.

According to short-term, distributed simulation training, implant placement with d-CAIS can help novice operators increase the precision of implant placement, with the high precision maintained when placing implants freehand as well. Although the precision at the platform level reached after training resembled that of an expert operator, novice operators required significantly more time and achieved significantly lower precision with angle and apex than the expert.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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