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Exploring training dental implant placement using computer-guided implant navigation system for predoctoral students: A pilot study

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Abstract

Introduction: Recent computer-guided dynamic navigation systems promise a novel training approach for implant surgery. This study aimed to examine learning progress in placement of dental implants among dental students using dynamic navigation on a simulation model.

Materials and Methods: Senior students with no implant placement experience were randomly assigned five implant placement attempts involving either three maxillary or four mandibular implants distributed in the anterior/posterior, and left/right segments. Implant placement was planned using a Navident Dynamic Guidance system. Surgical time was recorded. Horizontal, vertical and angulation discrepancies between the planned and placed implant positions were measured using superimposed CBCT scans. Data were analysed with repeated measures regression with Tukey's adjusted pairwise comparisons ($\alpha = 0.05$).

Results: Fourteen students participated, with a mean age of 26.1 years and equal males and females. Mean time for implant placement was associated with attempt number ($P < 0.001$), implant site ($P = 0.010$) and marginally related to gender ($P = 0.061$). Students had a significant reduction in time from their first attempt to their second (10.6 vs 7.6 minutes; adjusted $P < 0.001$) then plateaued. Overall 3D angulation ($P < 0.001$) and 2D vertical apex deviation ($P = 0.014$) improved with each attempt, but changes in lateral 2D ($P = 0.513$) and overall 3D apex deviations ($P = 0.784$) were not statistically significant. Implant sites were associated with lateral 2D, 2D vertical and overall 3D apex deviation ($P < 0.001$).

Discussion: Males were marginally faster than females, had slightly lower overall 3D angulation, and reported higher proficiency with video games. Novice operators improved significantly in speed and angulation deviation within the first three attempts of placing implants using dynamic navigation.

Conclusion: Computer-aided dynamic implant navigation systems can improve implant surgical training in novice population.

KEYWORDS

dental implants, education, navigation, simulation, students, surgery

1 | INTRODUCTION

Implant positioning in relation to planned definitive prostheses can be enhanced using computer-guided static or dynamic systems.[1-5] Static guided implant placement surgery involves the use of a cone beam computed tomography (CBCT) generated surgical guide with metal surgical tubes. These static guides can either be supported by adjacent natural teeth, mucosa or alveolar bone.[1-5] Static guided surgery has been shown to be more accurate than free hand implant placement.[1-5] Recent development of inexpensive three-dimensional (3D) printers allows cost-effective static guide fabrication and therefore have popularised the method.[4] Implant positioning is predetermined in a static guide; however, the static guide does not allow for real-time adjustments when needed or visualisation of the osteotomy. While tooth-supported or mucosal-supported static guided surgery is indicated with flapless surgery when bone grafting or osseous modification is not needed, static guided surgery can be difficult in patients with limited mouth opening, implant sites with difficult access or direct visualisation, as well as implant placement in limited horizontal spaces between adjacent teeth.[5]

Dynamic navigation surgery allows the operator to fully visualise the osteotomy and implant site on the computer screen while preparing the osteotomy site and placing an implant fixture. The accuracy of dynamic navigation has been observed to be comparable to that of static guided placement.[6] Dynamically guided implant placement has been shown to be more accurate than freehand implant placement in terms of angular deviation, platform positioning and apical positioning.[1,7-9] Most dynamic guided implant surgery studies however have been performed by experienced surgeons with prior training on the respective navigation system.[1,6] The question was raised whether dynamic navigation technology could be used to train the novice operator, such as a dental student with no previous implant surgical experience, to perform implant placement competently and accurately.

This prospective randomised study was designed to evaluate the learning progression, defined as accuracy in placement of dental implants on a simulation model, when a computer-guided dynamic navigation was used to train senior dental students with no previous implant placement training. Computer-guided dynamic navigation, such as Navident Dynamic Navigation used in this study, utilises virtual simulation and provides immediate feedback during the implant placement through interactive CBCT 3D modelling. The study was designed to define the learning curve and the minimal number of attempts necessary in utilising computer-guided implant navigation system to improve implant placement skill in a novice implant trainee. The main hypothesis was there was a statistical difference in implant sites measured by the improvement of implant placement accuracy and implant placement time. Additionally, the secondary hypothesis was that there was a statistical difference between males and females based on their implant placement improvement measured by the implant placement accuracy and time.

2 | MATERIAL AND METHODS

The study protocol was approved by the university Institutional Review Board, IRB No. HM20011878. Senior dental students with no prior surgical implant placement experience were recruited. A total of five implant placement attempts were assigned to each student. The first four attempts were randomly assigned for placing either three maxillary or four mandibular implants. Implant sites included maxillary first right molar, maxillary right central incisor, maxillary left first molar and mandibular left first molar, mandibular left second premolar, mandibular right second premolar, mandibular right first molar. The implant planning was done by the consultation of three authors who were board-certified prosthodontist (Author-SB), board-certified periodontist (Author JGD) and board-certified oral and maxillofacial surgeon (Author GRD). The implant site distributions were also randomly assigned for anterior/posterior as well as left/right on a simulation model. On the fifth attempt, the students placed implants on both jaws randomly assigned positions (anterior/posterior and left/right). A randomisation schedule was generated in SAS EG v6.1 software (SAS Institute) to assign all students to a random sequence of the first four jaws (two for maxilla and two for mandible), as well as the implant sites within each jaw for all attempts. The randomisation first assigned the students to a particular jaw and then randomised the implant sites within that jaw to reduce the logistical burden that randomising the implant sites would have brought (ie, changing jaws back and forth). Using the randomisation schedule, nine students began with the mandible and five students began with the maxilla. After each attempt, the participants completed questionnaires regarding to (a) previous dental simulation experience, simulations for caries preparation or restorative indications; (b) prior video gaming experience; and (c) perceived difficulty when using the navigation system to assist implant placement in regards to jaws (maxilla/mandible), sides (left/right) and implant sites (anterior/posterior). Prior to the first attempt, an orientation was done for each participant to explain how the study would be done, how the navigation system worked and how to use implant surgical handpiece and drills. A one-week washout period between each attempt was used.

Polymethylmethacrylate 3D printed maxillary and mandibular models were tagged with three fiducial markings, one placed on buccal aspect apically to the central incisors and the other two placed on the posterior aspect of the model. These markers ensured the three-dimensional orientation of the model in the CBCT and enabling accurate superimposition. A pre-operative CBCT scan using iCAT FLX V10 (Imaging Sciences International LLC) of the model was taken with a radiographic stent and fiducial markers in place. The data from CBCT were loaded into the Navident (Claronav) dynamic guidance system software where virtual implant placement including appropriate implant size (width and length) as well as implant position was planned. The spatial matching of the model to its virtual on-screen representation (CBCT image) was registered. The spatial relationship between the

JagTag on the stent installed on a plastic model and the DrillTag on handpiece was tracked by the stereoscopic camera. (Figure 1) The registration allowed for the continuous tracking of the jaw during the navigated osteotomy and for maintaining its accuracy if the jaw moves. (Figure 2) Note that the study used common manikin used in the US dental schools. All cases were done with the rubber simulated cheeks/soft tissue. However, it was difficult to take a photograph of drill angulation with the rubber cheeks in place. The implant placement figure therefore had no rubber cheeks to better demonstrate the drill angulation and positioning. The digital prosthetic set ups were performed and the crown positions were used for implant planning.

The model and the stent with the patterned jaw tag were tightly secured onto the mannequin. The Navident device was placed in front of the operator with the camera above the operating field. Appropriate positioning of the mannequin, camera, computer screen was ensured to enable easy visualisation of the computer screen displaying real-time feedback of the drill in relation to the planned implant position. Tracking system array from the camera to the jaw tag during the osteotomy preparation was used to accurately locate the position of the handpiece in relation to the model and scan. (Figure 1) Prior to osteotomy preparation for each drill, drill calibration was performed on the jaw tag to provide the system appropriate drill length. This in turns provided information on depth of the osteotomy preparation. A real-time video feedback throughout simulation, in relation to the planned implant position (with appropriate desired depth and angulation), was used to guide the implant site preparation and placement. The accuracy of the drill position and angulation in relation to the planned position of the implant was monitored and the deviations were allerted using a differential colour coded system (Figure 2).

Operating time was recorded for each attempt. All models were scanned in CBCT following implant placement. Superimposition of the pre-operative scan with planned implant position and the post-operative scan with placed implant position was performed using EvaluNav (Claronav) software through the three fiduciary markers (Figure 3). The planned and placed implant positions were compared (Figure 4). Repeated measures ANOVA was used to evaluate discrepancies in the two-dimensional (2D) lateral deviation, overall 3D apex deviation, 2D vertical apex deviation and overall 3D angle deviation (Figures 4 and 5). All models adjusted for the attempt number (1-5), implant site (maxillary right first molar, maxillary right central incisor, maxillary left first molar, mandibular left first molar, mandibular left second premolar, mandibular right second premolar and mandibular right first molar) and the gender of the operator. Post hoc pairwise comparisons were adjusted for using Tukey's HSD. SAS EG v.6.1 (SAS Institute) was used for all analyses. Significance level was set at $P = 0.05$. The null hypothesis was that there is no statistical difference in outcome measures (time, 2D discrepancies, 3D discrepancies) among the different implant sites and the gender of dental student operators. The study population was senior dental student volunteers. The outcome measures were the positional deviations of implant osteotomy and operation time. It was proposed that implant sites might influence the learning of implant placement and males might be better at learning implant navigation than females. Due to the nature of the pilot study, an a priori sample size calculation was not performed.

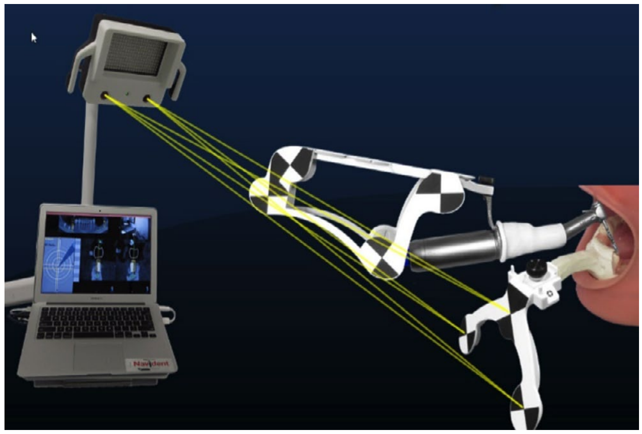

FIGURE 1 Schematics demonstrating the video camera detection of the handpiece position and jaw position through markers or tags

3 | RESULTS

A total of 14 senior dental students were participated in the study. The student participants were recruited through their clinical rotations in the oral & maxillofacial and periodontology clinics. Demographic data are presented in Table 1. Each student placed 21 implants within six jaws (three sites on three replicate maxillae, four sites on three replicate mandibles) using dynamic guided navigation. A total of 294 placed implants were assessed for time and accuracy

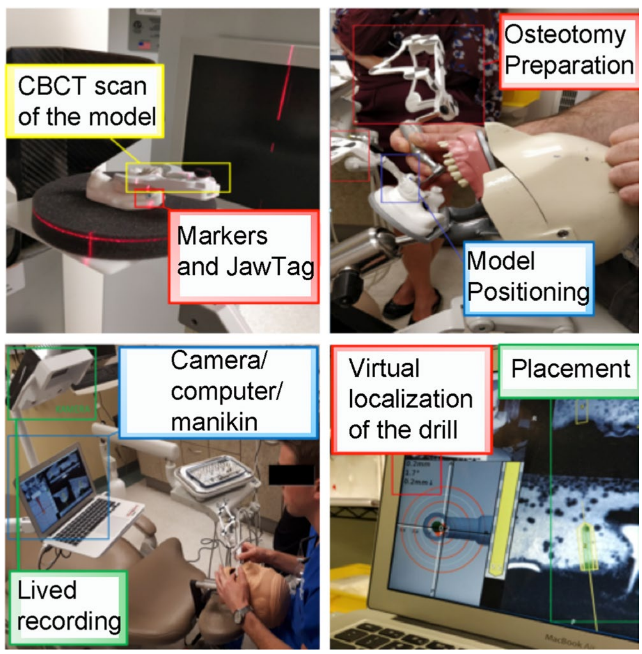

FIGURE 2 Experimental workflow

FIGURE 3 Automatic registration using fiduciary markers/tags (arrows)

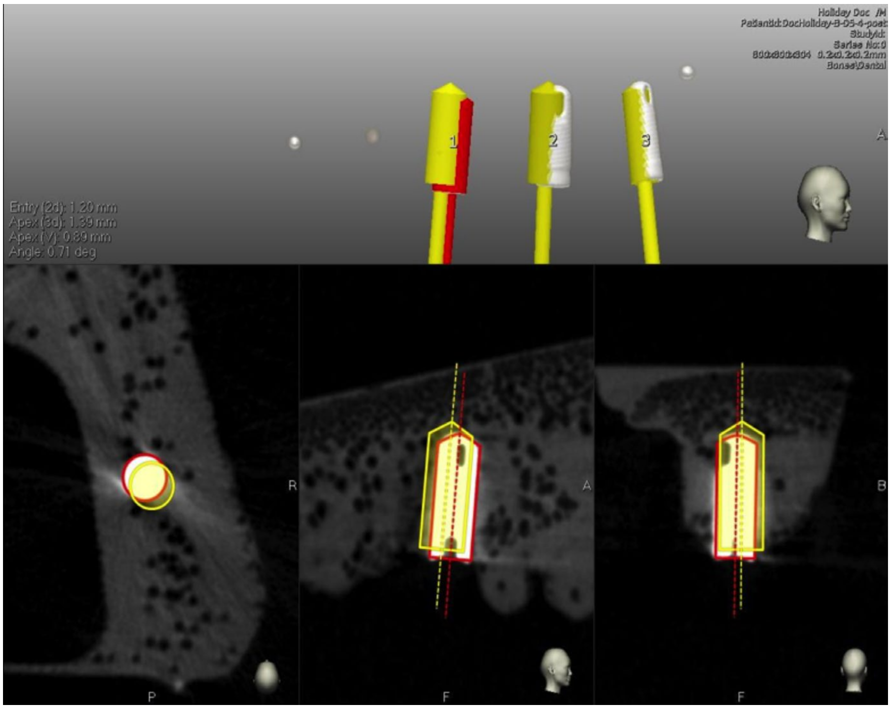

FIGURE 4 Superimposition of planned and actually placed implant positions

of placement. Statistical data were summarised in Tables 2 and 3. Time to place a given implant depended on the attempt number ($P < 0.001$), location of the implant ($P = 0.010$), and marginally depended on gender ($P = 0.061$; Table 4).

Time improved significantly between attempts 1 and 2 and then plateaued (Table 4, Figure 6). Implants placed in area of maxillary left first molar took significantly longer than other sites (Tukey's adjusted P-Value < 0.05 for all). After adjusting for attempt number and implant site, males were 1.91 minutes faster than females ($P = 0.061$). When analysing attempts for each jaw individually, time to place an implant improved significantly by the attempt number for maxilla ($P = 0.003$) and mandible ($P < 0.001$). Maxilla improved across all three attempts; mandible second and third attempts were not significantly different ($P = 0.96$; Figure 7). Maxillary left first molar implant site took the longest time for implant placement (9.1 minutes). Maxillary right central incisor site had the shortest time of 6.8 minutes (Figure 8).

Only implant location was significantly associated with differences in overall 2D lateral deviation ($P < 0.001$). Two-dimensional lateral deviation did not improve across attempts ($P = 0.513$) or differ between males and females ($P = 0.345$). Two-dimensional lateral deviation was lowest for maxillary right central incisor and highest for mandibular left first molar. (Table 5 and Figure 9).

The overall 3D angulation of the apex depended only on the implant site ($P < 0.001$), and did not improve across attempt ($P = 0.7840$) or between males/females ($P = 0.372$). Apex 3D angulation was the lowest for maxillary right central incisor and the highest for mandibular left first molar (1.37 vs 2.25, Table 5). The overall 3D angulation of the implant depended on attempt ($P = 0.0001$) and marginally on gender (0.067), but did not depend on implant site ($P = 0.145$). Overall 3D angulation improved significantly from attempt 1-2 and then plateaued (3.78 vs 2.87, Tukey's adjusted $P = 0.0264$; Figure 10). Males had marginally better accuracy (2.41 vs 3.35, Tukey's adjusted $P = 0.067$).

In addition to the objective outcomes, various subjective outcomes were also measured through the survey completed after each attempt. The post-experimental survey was done after all

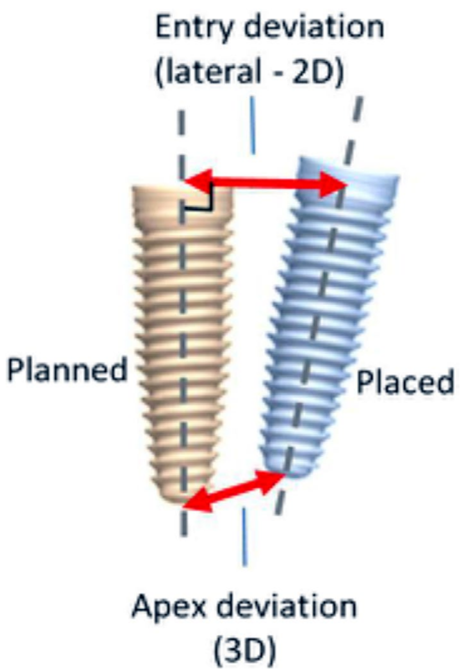

FIGURE 5 Apex deviation (3D) and entry lateral deviation (2D)

experiments were done for each participant. The survey was intentionally used only after the experiments to minimise participant's bias by limited their knowledge about the system. Perceived bimanual stabilisation of the hand piece improved significantly across attempts ($P = 0.024$; seven average or below on first attempt vs 0 by sixth attempt). All students (who were all right-handed) perceived left side as more challenging than right, similar to speed and accuracy measures. Students reported roughly equal split between which jaw was easier: 58% maxilla vs 42% mandible. Males reported marginally better video gaming skills than females ($P = 0.10$; 43% strongly agree vs 0%), which may be related to the marginal differences in objective outcomes.

Since an a priori sample size calculation was not possible, a post hoc power analysis was performed to determine the detectable difference for each outcome based on significance level of 0.05, 80% power, and 14 subjects with 21 repeated measures (21 total implants placed). Using the observed variance and correlation between repeated measures (assuming compound symmetric structure), we had power to detect a difference in time of 1.8 minutes, 2D lateral deviation of 0.24 mm, 2D vertical apex deviation of 0.21 mm, overall 3D apex deviation of 0.21 mm and overall 3D angulation of 0.93°. These detectable differences are all large enough to indicate clinical meaningfulness yet small enough to suggest statistical validity.

TABLE 3 *P*-Values for repeated measures ANOVA models

	Attempt	Location	Gender
Time	**<0.001**	**0.010**	**0.061**
Lateral 2D	0.513	**<0.001**	0.345
Overall 3D apex	0.784	**<0.001**	0.372
2D vertical apex	**0.014**	**<0.001**	0.767
Overall 3D angulation	**<0.001**	0.1447	**0.067**

Numbers in bold refer to statistical significant values.

TABLE 1 Demographics

	Mean	SD
Age	26.1	1.77
	n	%
Sex		
Male	7	50%
Female	7	50%
Dominant hand		
Right	13	93%
Left	1	7%

4 | DISCUSSION

It is interesting to note that computer-aided/assisted implant treatment planning, also known as virtual implant treatment planning, has been used widely in the predoctoral dental implant education.[10,11] Dental treatment model simulation has been widely used in dental education.[12] However, it is important to point out that these simulation models are hypothetical and cannot be used in humans. Dental implant navigation systems however are being used clinically. Only one study demonstrated that dental implant navigation system can be used to enhance implant placement training in the predoctoral

TABLE 2 Summary statistics by attempt number

	Attempt (mean, SD)				
	1	2	3	4	5
Time (in min)	10.5, 3.93	7.5, 3.58	7.9, 4.05	7.4, 3.52	6.4, 2.88
Deviations					
Lateral 2D	1.2, 0.64	1.2, 0.54	1.2, 0.72	1, 0.6	1.1, 0.62
Overall 3D apex	1.9, 0.74	1.9, 0.53	1.7, 0.66	1.7, 0.66	1.7, 0.77
2D Vertical apex	1.1, 0.51	1.3, 0.58	1.2, 0.54	1, 0.63	1.0, 0.62
Overall 3D angulation	3.7, 2.33	2.9, 1.52	2.8, 1.80	2.6, 1.63	2.5, 1.46

TABLE 4 Factors associated with time to place implant

	Estimated* mean time (in min)	SE	P-Value	
Attempt			<0.001	
1	10.65	0.60		a
2	7.55	0.60		b
3	7.62	0.61		b
4	7.39	0.61		b
5	6.41	0.52		b
Location			0.010	
3 (Maxillary right first molar)	8.24	0.63		a, b
8 (Maxillary central incisor)	7.19	0.63		a
14 (Maxillary left first molar)	9.51	0.63		b
19 (Mandibular left first molar)	8.14	0.62		a
20 (Mandibular left second premolar)	7.45	0.63		a
29 (Mandibular right second premolar)	7.52	0.63		a
30 (Mandibular right first molar)	7.41	0.63		a
Gender			0.061	
Male	6.97	0.65		a
Female	8.88	0.65		b

*Results from repeated measures ANOVA with Tukey's adjusted post hoc comparisons; levels with the same letter were not.

dental students compared to conventional freehand osteotomy preparation.[13] While this particular study demonstrated that students when using navigation system can place implants in vitro more accurately than freehand technique, the investigators did not look at the learning curve or if there was any difference based on implant sites or gender of students.

This study was perhaps one of the first to demonstrate that there was a clear learning curve in training novice implant surgeons using computer-guided implant navigation system. The results demonstrate three important findings. First, the hand skill was improved within the first three trial attempts and then plateaued out thereafter. This implies that using computer-guided trainees with no implant placement experience would need at least three trials before they would be comfortable in placing an implant with optimal positioning in a timely manner. In other surgical fields, such as laparoscopic surgery, endovascular surgery or surgical endoscopy, computer-guided simulation has and continues to be used for training and evaluation of progression of surgical aptitude and competency.[14-17] It has been demonstrated that in these very different surgical fields, surgical adeptness and learning curve improved with training using computer-guided simulation systems.[14-17] Student learning in this study was evaluated through improved performance over time during acquisition of a new skill. While ideally a control group of other intervention should be added, the study used the first implant placement attempt as the baseline or internal control group. Performance was evaluated through improved time and accuracy of placement of the implant fixtures aided by guided navigation. In this study, the time required for osteotomy and placement of implants significantly improved between first and second attempt and consequent attempts showed only slight continued improvement across time. This supports the learning model through virtual reality feedback and guidance. Since virtual feedback during implant placement with dynamic navigation is enabled by camera tracking with tracking tags on model and handpiece, it is imperative to keep those unblocked in full view for tracking array system.

Second, the learning curves are different based on the implant site. Implant site randomisation was used to control the experimental bias. The deviations of the implants were recorded using the software in real time and therefore there was no need

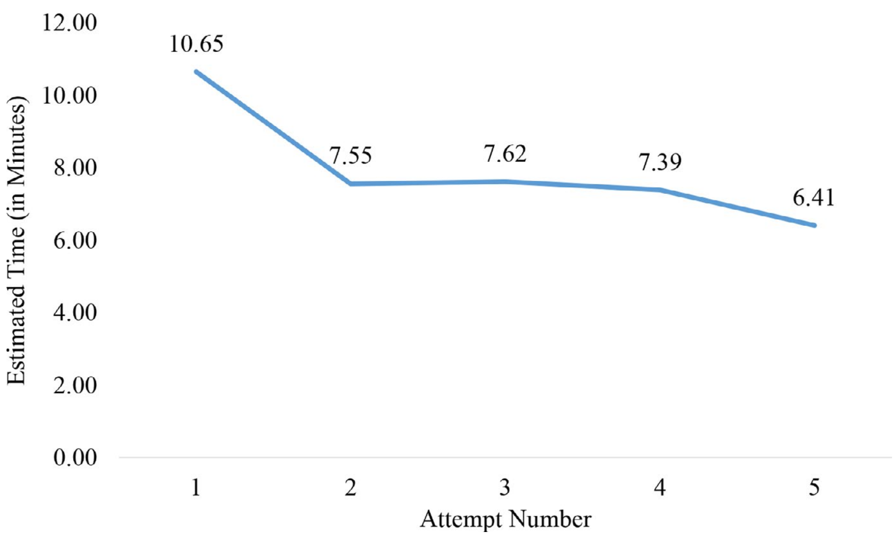

FIGURE 6 Average implant placement time by attempt number

FIGURE 7 Average time by attempt and jaw

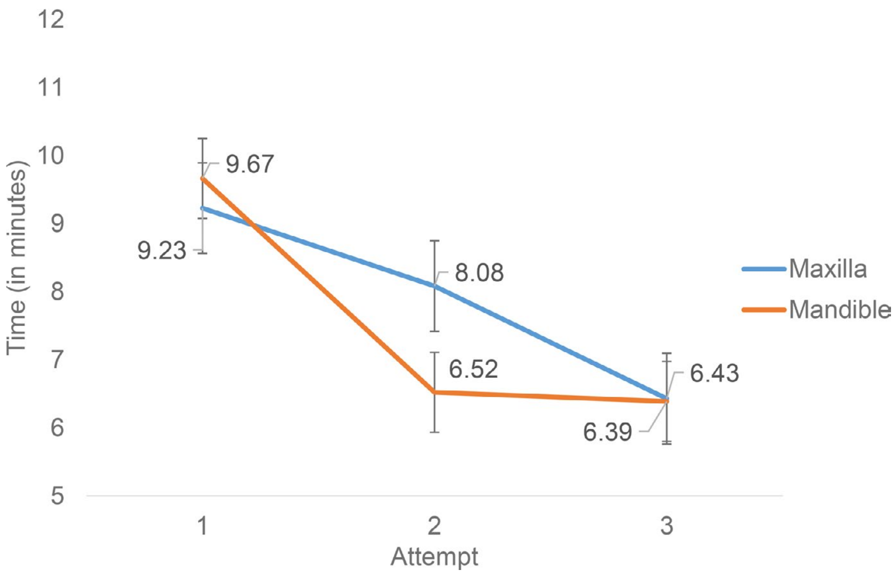

FIGURE 8 Average time by implant site

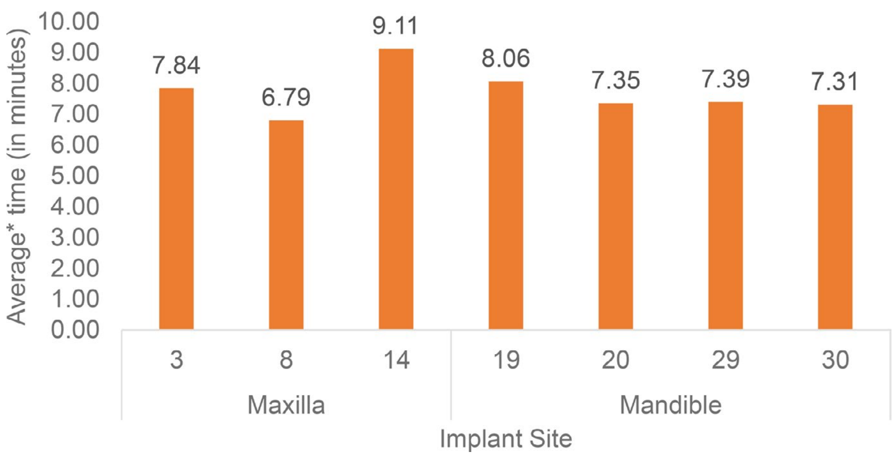

TABLE 5 Comparison of deviation by implant site

	2D Lateral deviation ($P<0.001$)			2D vertical apex deviation ($P<0.001$)			3D apex deviation ($P<0.001$)		
Location	Mean* deviation	SE		Mean* deviation	SE		Mean* deviation	SE	
Maxillary right first molar	1.01	0.10	a, b	1.08	0.09	a, b, c	1.67	0.10	b, c, d
Maxillary right central incisor	0.79	0.10	b	0.86	0.09	c	1.37	0.10	d
Maxillary left first premolar	1.18	0.10	b, c	0.97	0.09	a, b, c	1.52	0.10	c, d
Mandibular left first molar	1.50	0.10	c	1.50	0.09	d	2.25	0.11	a
Mandibular left second premolar	1.41	0.10	c	1.29	0.09	a, d	2.08	0.11	a, b
Mandibular right second premolar	1.20	0.10	b, c	0.92	0.09	b, c	1.73	0.11	b, c, d
Mandibular right first molar	0.91	0.10	a, b	1.25	0.09	a, b, d	1.80	0.11	b, c

*Adjusted for attempt and gender; levels joined by the same letter were not statistically significantly different; overall 3D deviation did not depend on implant site.

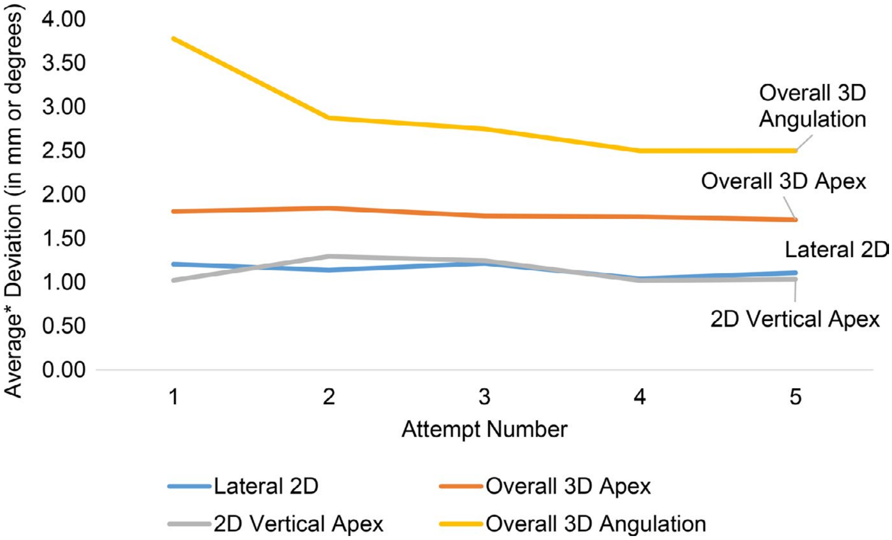

FIGURE 9 Average deviation by attempt number

of an external evaluator. Anterior implant sites are easier to learn to place implants than the posterior ones. For this right-handed group, the posterior left is the most difficult site to learn. This learning curve appears to be similar to static guided surgery.[18] In this study settings, the stents used on the models have been prefabricated uniformly, with the JawTag placed in only one position in relation to the model, regardless of the location of the surgical site. A possible result of that was that the right side and mandibular placement proved to be much easier, possibly explaining the findings from actual time and accuracy as well as perceived difficulty related to certain implant sites. Depth of placement and adjacent teeth demanded the use of extenders in lower left quadrant. Extender renders the drill much longer and less rigid, hence introducing longer distance from the handpiece to the tip of the drill which may affect calibration and accuracy. This could offer a subjective explanation for self-reported student perception that implant placement in lower left quadrant was more difficult. Objectively, that perception can be supported by longer times for placement on lower left compared to lower right side. Despite the improvements in operative or procedural time, there was minimal improvement in deviation suggesting that once students get comfortable with procedure their accuracy does not improve any further corresponding with improved efficiency and that the guided navigation system allows for a stable amount of accuracy.

Third, there were slight learning advantages in the male trainees possibly due to the experience in computer gaming. Overall 3D angulation, arguably the best measure for overall accuracy, improved overtime but most significantly by attempt number two as students gained more familiarity and implementations of skills responding to navigation feedback information improved. In that perspective, video gaming appears to be beneficial in adaptive learning to interactive virtual guidance. It is noteworthy that overall males had faster implant time placement and better overall 3D angulation but this may be related to prior video gaming experience. As male students reported greater experience with video games may offer an explanation on why males are better.[19,20] The serious gaming concept has been associated with enhancement of skill progression and simulator validation in surgical trainees.[19,20] Some limitations of the study include the limitation of post-experimental survey, no traditional implant training control, and no prior information on possible related

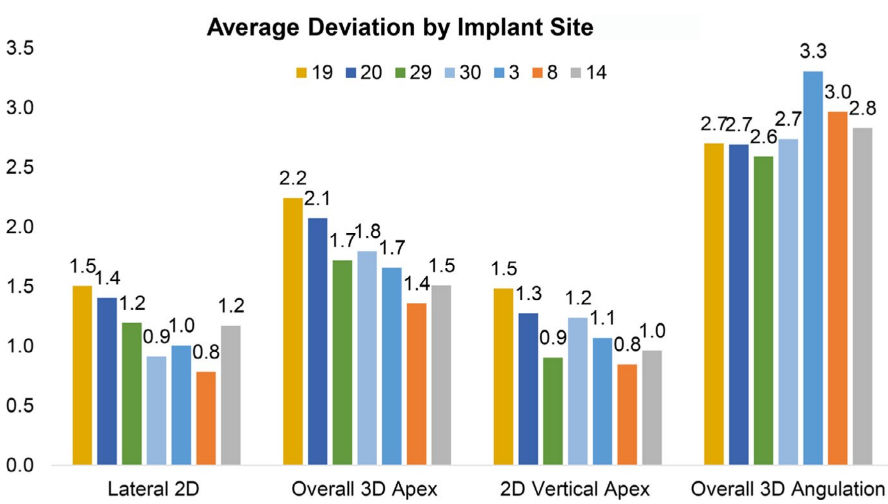

FIGURE 10 Average deviation by implant site

skills such as computer gaming experience. It is also important to emphasise that the study is a pilot study with a small sample size in students with limited knowledge of implantology. Future larger study should be done in variety of implant surgical skill and knowledge.

Dynamically guided systems may present a teaching tool in early development of clinical skills in implant placement for the novice operator. This interactive model may allow for the development of neural pathways through biofeedback and may be beneficial in achieving more optimal clinical results in the early phase of surgical implant training. Novice operators often struggle with achieving correct drill position in certain areas of the mouth, in particular in posterior sites opposite to the operator's dominant hand. It should be kept in mind that clinical scenarios can be more complex beyond just the accuracy of osteotomy preparation and simulated experience is no substitute for live clinical experience. Future studies should include examining the role of previous computer gaming skill and trainee's gender, the longer period of training as well as a randomised controlled trial to compare the navigation technology with traditional implant surgery training. It will also be interesting to see whether the navigation system can be used to train students for other implant-related surgical procedures such ridge augmentation, and sinus grafting. While this study showed a statistical significance in the improvement of implant placement using navigation system, it did not prove if the navigation is better or worse than conventional training. Future studies should include the comparison between navigation training and conventional technique. The implant planning and issue of experienced vs inexperienced surgeon that were unfortunately beyond the scope this study should also be addressed in future studies.

5 | CONCLUSION

Novice operators demonstrate significant improvement of implant placement skills with dynamic navigation within three attempts. The speed and angulation deviation improve significantly within the first three attempts and are sustained. Performance for males, on average, was marginally better in time and accuracy than females.

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