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ORIGINAL ARTICLE

Evaluation of a dynamic navigation system for training students in dental implant placement

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Abstract

Objective: Computer-guided simulation systems may offer a novel training approach in many surgical fields. This study aimed to compare dental students' learning progress in dental implants placement between a dynamic navigation system and a traditional training method using a simulation model.

Methods: Senior dental students with no implant placement experience were randomly assigned to implant placement training using a dynamic navigation system or a traditional freehand protocol. After training, 3-dimensional (3D) deviation at implant platform, 3D deviation at implant apex, and deviation of implant axis between the planned and placed implant positions were measured using superimposed cone beam computed tomography scans.

Results: Six students were trained in this study. Students showed significantly greater improvement in implant placement after training using the dynamic navigation system than after using the traditional freehand protocol. Overall deviation of implant axis ($P < 0.001$) and 3D apex deviation ($P = 0.014$) improved with training using the dynamic navigation system, but differences in 3D platform deviation ($P = 0.513$) were not statistically significant.

Conclusions: A dynamic navigation system may be a useful teaching tool in the early development of clinical skills in implant placement for the novice practitioners. Novice practitioners exhibited significant improvement in angulation deviation across implant placement attempts with dynamic navigation system training.

KEYWORDS
computer-assisted instruction, computer simulation, dental implant, dynamic navigation, dental education, simulation surgery

1 | INTRODUCTION

Implant osseointegration is presumed to be highly predictable.[1] Appropriate implant position is considered essential for ensuring successful treatment outcomes and for long-term maintenance of the function and the peri-implant tissue health. Compromised implant position predisposes patients to poor outcomes and short-term or long-term complications.[2,3] However, the predictability of implant placement according to the prosthetic requirements is a challenge. Experienced surgeons with prior training in implant placement can place dental implants accurately in terms of position, depth, and angulation. Traditional methods of training using freehand implant placement on models cannot provide reliable guidance for implant placement at the optimal planned position in novice practitioners. As a form of digital technology applied to the medical field, computer-assisted implant surgery was introduced in 1995 to allow for accurate achievement of the planned optimal implant position.[4] Computer-guided implant dynamic navigation systems are available to assist in presurgical virtual planning of the optimal 3-dimensional (3D) implant position and the transfer to surgical implant placement.[5]

Dynamic navigation systems use motion tracking technology to track implant drilling instruments and the position of the patient's jaw in real-time on the monitor superimposed to the virtual plan. The 3D deviation of the drill or implant from the virtual planned position can be observed in real-time on a monitor; the drilling depth, angle, and implant position can be adjusted at any time. Recent developments in technology have also created the changes in dental education, such as the use of simulation and virtual reality systems.[6–11] Dental educators who are charged with training students and novice practitioners continuously seek the best methods for teaching and training students in clinical skills. The question addressed in this study was whether dynamic navigation technology could be used to train the novice practitioners (such as dental students without previous implant surgical experience) to perform implant placement competently and accurately.

The purpose of this study was to compare learning progression toward accuracy in dental implant placement using a dynamic navigation system and a traditional freehand protocol, such as that typically used to train novice practitioners without previous implant placement experience on a simulation model. Additionally, the study investigated the learning curve for use of dynamic navigation to improve implant placement skill in novice implant trainees.

2 | MATERIALS AND METHODS

The institutional review board waived the requirement for ethical approval for this study. Six senior dental students without prior surgical experience performing dental implant placement were recruited and randomly allocated to the traditional training and dynamic navigation training groups. A computer-generated, randomly permuted block randomization process was performed by a colleague in the absence of the study investigators, using a software program. Group assignments were concealed in opaque envelopes until immediately before training. The evaluator and statistical analyst were blinded to the training plan and to participant groupings. Each student was instructed to place a single implant to replace a maxillary left first molar. Implant planning was performed in consultation with a board-certified prosthodontist (Author-LF) and a board-certified oral and maxillofacial surgeon (Author WMZ). Detailed instructions for the drilling assignment for the dental implant indicated the location, drilling angle, and drilling depth. Before the implant placement was performed, the instructions were reviewed and a video demonstrating the surgical execution was screened. The instructions and the video were available to the students throughout the surgery. For each model, the implant site drilling hole was prepared and a 4.1 * 10 mm implant (Straumann, BL, Switzerland) was placed to simulate rehabilitation of the missing maxillary left first molar.

The 3D-printed polymethylmethacrylate maxillary models were tagged with an acrylic resin radiographic guide; radiopaque markers were placed along the buccal and palatal flanges. These markers allowed visualization of the 3D orientation of the model and enabled accurate superimposition on cone-beam-computed tomography (CBCT). Silicone rubber was used to stabilize the radiographic guide during the CBCT scanning. A preoperative CBCT scan of the model, taken using the cs9300 (Carestream Health, NY, USA) was performed with a radiographic stent and fiducial markers in place. The CBCT data were loaded into the dynamic guidance system (Yizhimei, Suzhou, China) software; virtual implant placement was planned, including appropriate implant size, as well as implant position and orientation. Digital prosthetic setup was performed, then used for implant planning. Prior to the first attempt, an orientation was provided for each participant to explain how the study would proceed, how the navigation system worked, and how to use the surgical handpiece and drills.

In both groups, the first 5 attempts were assigned for freehand placement (Figure 1). In subsequent attempts, freehand placement was used to train students in the traditional training group; dynamic navigation was used to train students in the dynamic navigation training group (Figure 1).

In the dynamic navigation system, the initial step was registration of the spatial matching of the model to its virtual on-screen representation. The spatial relationship between the model and handpiece was tracked by the stereoscopic camera (Figure 2A). The registration allowed continuous tracking of the model during osteotomy navigation and maintenance of accuracy when the model moved (Figure 2B). Appropriate positioning was required to enable easy visualization of the computer screen, which displayed real-time feedback regarding the relationship of the drill to the planned implant position (Figure 2C). During site preparation, the tracking system was used to

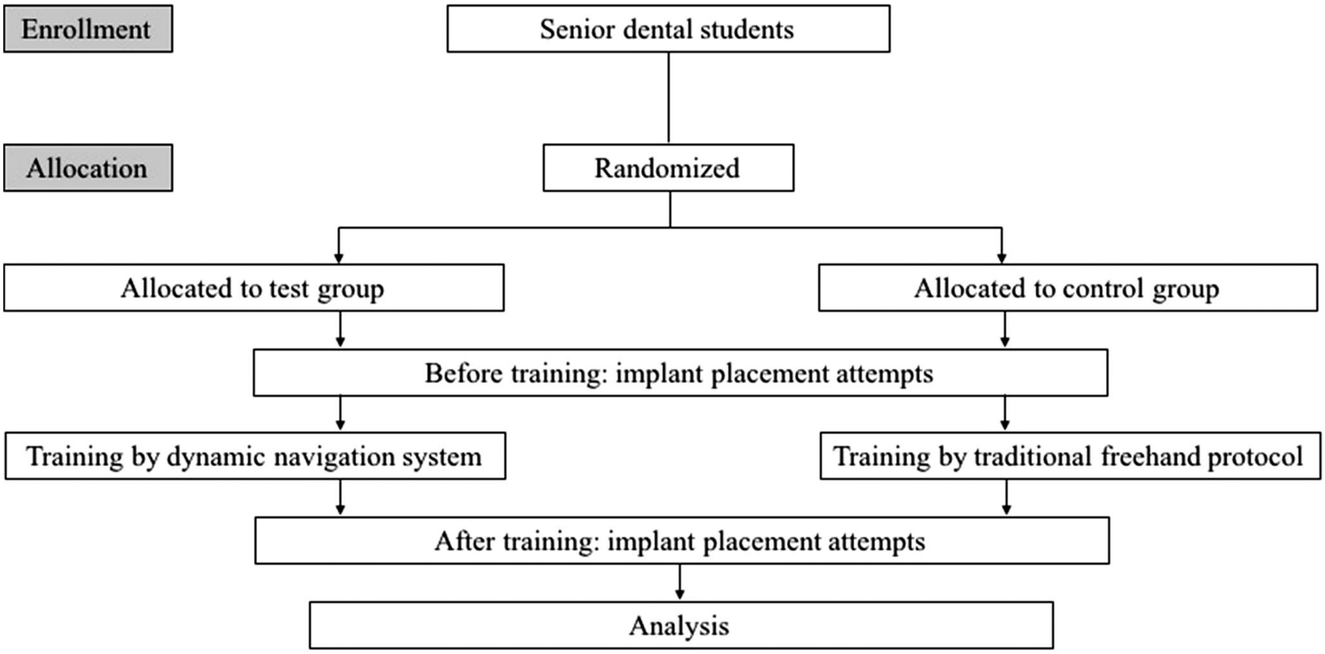

FIGURE 1 Cohort flowchart of the study

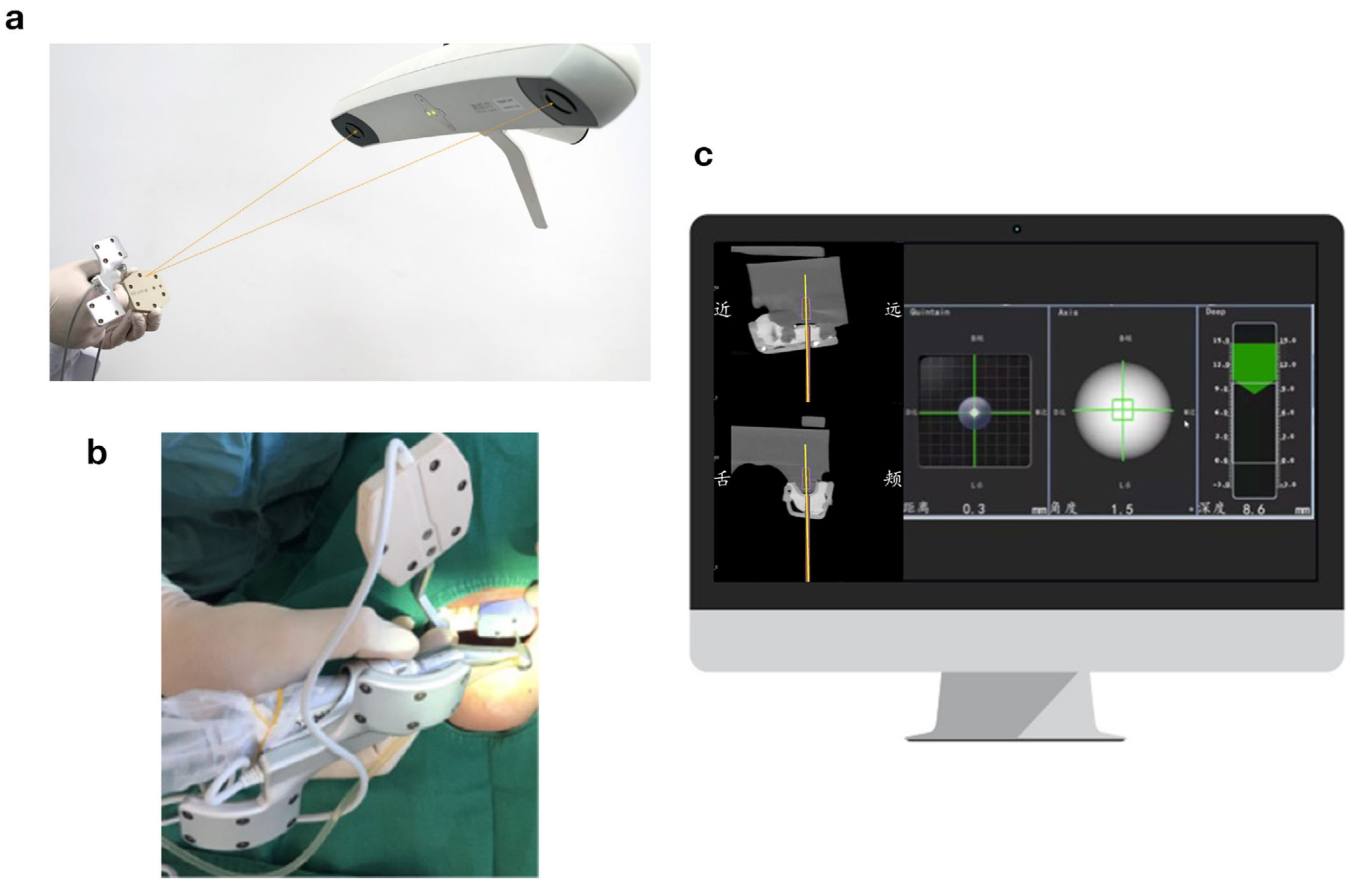

FIGURE 2 Training in placement of dental implants using dynamic navigation system. Video camera detection of the handpiece position through tags (A); video camera detection of the model position through markers (B); visual location of the drill and implant placement on the computer monitor (C)

accurately locate the position of the handpiece with respect to the model and the scan (Figure 2). Prior to each drill use, calibration was performed to provide the system with appropriate drill length, which then provided information regarding the depth of site preparation. Real-time video feedback throughout the simulation was used to guide the osteotomy preparation and placement with respect to the planned implant position. Thus, the accuracy of the drill position and angulation relative to the planned implant position was monitored. The deviation was warned using a color-coded system (Figure 2C).

After training, all students were instructed to complete the final 5 attempts using freehand implant placement. Finally, students were instructed to complete questionnaires regarding previous dental simulation experience and prior video gaming experience. Students used a scale from 1–10 (10 is best) to evaluate the training and the degree to which they learned dental implantation from the training. Students in the dynamic navigation group were also asked whether they would choose to use the dynamic navigation system to perform dental implantation; if they would not, they were asked to provide an explanation.

Following implant placement, all models were scanned by CBCT using the acrylic resin radiographic guides. Superimposition of the preoperative scan with the planned implant position and the postoperative scan with the placed implant position was performed using EvaluNav (Claronav) software in combination with radiopaque markers (Figure 3A and B); the planned and placed implant positions were compared (Figure 3C and D). The superimposition and measurement were accomplished by a single calibrated and blinded examiner. The deviations of the placed implant positions relative to the planned implant position were compared between before training and after training, as well as between the 2 training groups after training. Repeated-measures ANOVA was used to evaluate discrepancies in the 3D deviation at implant platform, 3D deviation at implant apex, and deviation of implant axis (Figure 3). Post hoc pairwise comparisons were adjusted for using Tukey's HSD. IBM SPSS Statistics, version 22 (Chicago, IL, USA) was used for all analyses.

3 | RESULTS

Student participants were recruited through their clinical rotations in the First Clinical Division, Peking University School and Hospital of Stomatology. All students were right-handed. In total, 60 placed implants were assessed to evaluate the accuracy of placement.

The accuracy of implant placement before training did not significantly differ between the traditional freehand training and dynamic navigation training groups (3D deviation at implant platform: 1.893 ± 0.609 vs. 1.988 ± 0.444, $P > 0.05$; 3D deviation at implant apex: 2.412 ± 0.698 vs. 2.394 ± 0.711, $P > 0.05$; Deviation of implant axis: 5.130 ± 2.087 vs. 5.288 ± 2.653, $P > 0.05$). The accuracy of implant placement significantly improved during training in the dynamic navigation training group (Figures 4 and 5). The 3D deviation at implant apex (2.394 ± 0.711 vs. 1.626 ± 0.430, $P = 0.014$) and deviation of implant axis (5.288 ± 2.653 vs. 2.898 ± 1.474, $P < 0.001$) improved across attempts using the dynamic navigation system (Figure 4). After dynamic navigation training, the accuracy of implant placement significantly improved, relative to the accuracy achieved with traditional training (3D deviation at implant apex: 1.626 ± 0.430 vs. 2.275 ± 0.403, $P < 0.001$; Deviation of implant axis: 2.898 ± 1.474 vs. 4.342 ± 2.179, $P < 0.05$) (Figure 4). After training using the dynamic navigation system, the students improved in deviations within the last 5 attempts of placing implants (Figure 5).

In addition to the objective outcomes, subjective outcomes were evaluated. Each student completed a postexperiment survey after all experiments had been completed. The surveys were intentionally administered only after the experiments to minimize participants' bias due to limited knowledge regarding the system. Perceived bimanual stabilization of the handpiece significantly improved across attempts. Most participants in this study considered their execution to have improved by repeating the assignment in either the traditional training group or the dynamic navigation group. Indeed, the degree of learning scores in this study were 9.1 for the navigation group and 8.3 for the traditional group. All students (100%) in the dynamic navigation training group expressed the desire to use the dynamic navigation system for implantation in the future.

Because prior sample size calculation was not possible, a post hoc power analysis was performed to determine the detectable difference for each outcome based on a significance level of 0.05, and 80% power. Using the observed variance between these repeated measures, this study exhibited sufficient power to detect a difference in 3D deviation at implant platform of 0.45, 3D deviation at implant apex of 0.39, and deviation of implant axis of 1.13. These detectable differences were sufficiently large to indicate clinical meaningfulness yet sufficiently small to suggest statistical validity.

4 | DISCUSSION

Optimal 3D implant placement is important in dental implant restoration in order to ensure appropriate prosthesis design; it also facilitates proper function, satisfactory esthetics, and peri-implant tissue health.[12–14] Dental simulation model and virtual implant planning has been

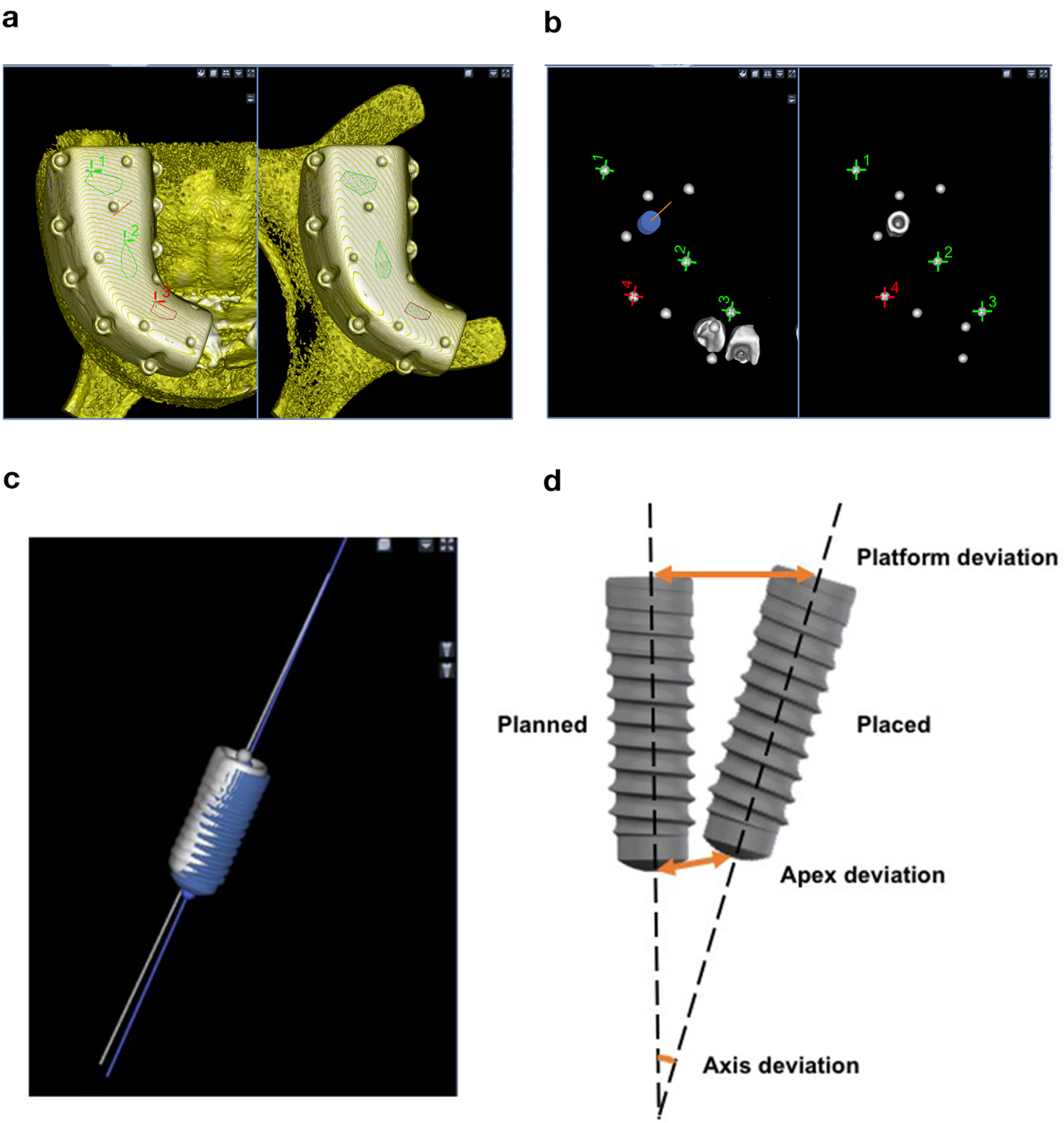

FIGURE 3 Superimposition of the preoperative scan with planned implant position and the postoperative scan with the implant in place was performed using EvaluNav (Claronav) software through radiopaque markers (A and B). Superimposition of the planned implant positions and actual placement (C) and the deviation of implant placement from the planned positions were measured (D)

used widely in dental implant education.[15–17] It is important that coming the virtual implant planning true in the edentulous alveolar ridge. However, implant placement in a precisely planned position requires abundant experience; thus, a learning curve is inevitable. Dynamic navigation systems have been used to accurately transfer a digitally planned optimal 3D implant position to the surgical site. Accordingly, a dynamic navigation system was used to facilitate implant placement in the planned position; the ability of dynamic navigation training to accelerate the learning curve was assessed.[18,19] The present study demonstrated that a dynamic navigation system could be used to enhance implant placement training of dental students, compared to traditional freehand osteotomy preparation.

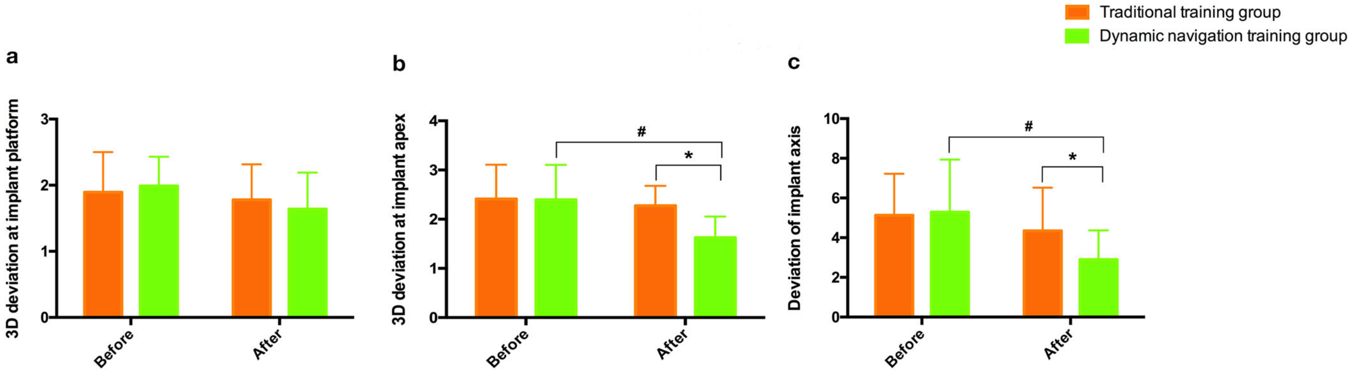

FIGURE 4 Deviation of the placed implant from the planned position was compared between the traditional training and dynamic navigation training groups before and after training. 3D deviation at implant platform (A), 3D deviation at implant apex (B), and deviation of implant axis (C). Data are presented as means ± SD. The accuracy of implant placement before training was no significant difference between traditional training group and dynamic navigation training group ($P > 0.05$). In dynamic navigation training group, 3D deviation at implant apex and deviation of implant axis improved significantly after training compared to before training ($P < 0.05$), and the implant placement were more accurate than traditional training group ($P < 0.05$). ($^*P < 0.05$, dynamic navigation training group vs. traditional training group; $^{\#}P < 0.05$, after training vs. before training)

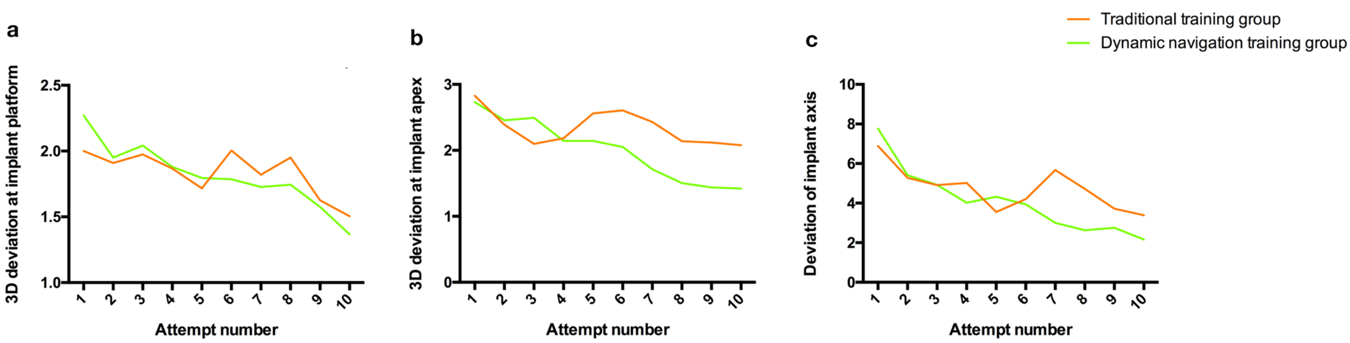

FIGURE 5 Average deviation by attempt number in traditional training group and dynamic navigation training group. Before training, the deviations of the placed implant positions relative to the planned implant position within the first 5 attempts (attempt number 1–5) were recorded. After training, the deviations within the last 5 attempts (attempt number 6–10) were recorded. 3D deviation at implant platform (A), 3D deviation at implant apex (B), and deviation of implant axis (C)

When placing implants in vitro, students using the navigation system were able to place the implants more accurately, compared to those using the freehand technique. This virtual reality simulation might provide better objective feedback and improve students' manual skills without the risk of harm to a patient.

In many surgical fields, such as endoscopy, laparoscopy, and endovascular surgery, computer-guided simulation has been used for training and for evaluating the progression of surgical competency.[20–23] Notably, surgical adeptness has been improved through training using computer-guided simulation systems.[20–23] Previous studies have demonstrated that virtual reality systems could be used as a teaching tool.[24,25] Several studies have shown that virtual reality systems improved trainees' performances, whereas others found no benefit relative to training with the traditional protocols.[7,8,10,21,26–28] In this study, we examined the efficiency of learning dental implant placement using a dynamic navigation system. Students learning by means of traditional freehand intervention served as a control group to evaluate the benefits of the dynamic navigation system for implant skill acquisition and performance improvement. In addition, implant placement attempts before training were used as the baseline and internal control group. Improvement in implant placement accuracy was evaluated after training. Manual skill improved more rapidly and to a greater extent when using the dynamic navigation system, compared to traditional implant training. The freehand training group showed minimal improvement in implant placement deviation, suggesting that when students became comfortable with the procedure, their accuracy did not show further improvement. In contrast, the dynamic navigation system allowed for consistency and improved accuracy; it provided substantial improvement in terms of implant orientation and safety, particularly in complex anatomical regions.

Notably, the students indicated that the dynamic navigation system improved their performance; their mean rating score was 9.1, suggesting that implant placement was easier after training using the dynamic navigation system. This finding was consistent with data that indicated students in the dynamic navigation group tended to perform better. Finally, students who used the dynamic navigation system for training wished to continue using it in the future.

The overall deviation of implant axis, the best measure of overall accuracy, was most improved by dynamic navigation system training, because students gained more skills through responses to navigation feedback. From that perspective, video gaming appears to be beneficial for adaptive learning with regard to interactive virtual guidance,[29,30] which can be attributed to the real-time guidance and feedback provided by the system that informing the student about his or her location and about deviations from the ideal plan, permitting drilling correction in real time.

Proficiency in implant placement is known to require a learning curve that involves numerous surgical practices experiences.[31] The dynamic navigation system provides a teaching tool during early development of implant skills for the novice practitioners. The interactive model of the dynamic navigation system may allow for development of neural pathways through biofeedback and may be beneficial for achieving better clinical results during the early phase of implant surgery training. Novice practitioners often struggle to achieve correct drill positions in certain areas of the mouth, particularly in posterior sites opposite to the operator's dominant hand, such as the maxillary left posterior site for a right-handed surgeon. The present study showed a statistically significant improvement in implant placement at the maxillary left first molar when using the dynamic navigation system. Nevertheless, clinical cases are likely to present complexities beyond the accuracy of osteotomy preparation and simulated experience; thus, these learning sessions are no substitute for real-world clinical experience. Furthermore, it remains unknown whether the dynamic navigation system can be used to train students for other implant-related surgical procedures, such as ridge augmentation and sinus augmentation. Comparisons of experienced and inexperienced surgeons were unfortunately beyond the scope of this study; these questions should be addressed in future studies. This was a pilot study with a small sample size, and the participants were students with limited knowledge of dental implantology. Future studies should include a variety of implant sites and a range of implant surgical skills.

5 | CONCLUSIONS

Novice practitioners demonstrated significant improvement in their implant placement skills after training with a dynamic navigation system. The results of this study suggest that practical training in dental implantation using a dynamic navigation system should indeed be part of dental education. Additional studies are necessary to determine the best approach for implementation of dynamic navigation systems to train students in dental implant surgery.

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CONFLICT OF INTEREST

The authors report no conflict of interest related to this study.

FINANCIAL DISCLOSURE

The authors have no financial interests relevant to this article to disclose.

AUTHOR CONTRIBUTIONS

Yalin Zhan drafted the manuscript, conducted data acquisition and analyses, interpreted results, and reviewed. Miaozhen Wang conducted data curation, interpreted results, reviewed, and revised the manuscript. Xueyuan Cheng conducted data acquisition and interpreted results. Yi Li interpreted results and reviewed the manuscript. Xiaorui Shi provided contributions to the conceptualization and the design of the study and reviewed the manuscript. Feng Liu provided contributions to the conceptualization and the design of this study, interpreted results, reviewed, and revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of this study.

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