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Comparison of the accuracy of two different dynamic navigation system registration methods for dental implant placement: A retrospective study

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Abstract

Background: Dynamic navigation approaches are widely employed in the context of implant placement surgery, with registration being integral to the accuracy of such navigation. Relatively few studies to date, however, have compared different registration approaches, and such a comparison has the potential to guide the development of more accurate and reliable clinical registration methodology.

Purpose: This study was developed to compare the accuracy of dynamic navigation-based dental implant placement conducted using either U-tube or cusp registration methods.

Materials and Methods: Medical records from all patients that had undergone implant surgery between August 2019 and October 2020 in the First Clinical Division of the Peking University Hospital of Stomatology were retrospectively reviewed, with 64 patients and 99 implants ultimately meeting with study inclusion criteria. Implant placement accuracy was gauged via the superimposition of the planned implant position in preoperative cone-beam computed tomography (CBCT) images with the true postoperative implant position in postoperative CBCT images. Accuracy was measured based upon the angular deviation, entry deviation (3-dimensional [3D] deviation in the coronal aspect of the alveolar ridge), and apex deviation (3D deviation in the apical area of the implant) when comparing these two positions.

Results: The angular deviation, entry deviation, and apex deviation of all analyzed implants were 3.29 ± 0.17°, 1.29 ± 0.07 mm, and 1.43 ± 0.08 mm, respectively, while in the cusp registration group these respective values were 3.25 ± 1.58°, 1.28 ± 0.60 mm, and 1.34 ± 0.63 mm as compared to 3.35 ± 1.78°, 1.30 ± 0.78 mm, 1.55 ± 0.9 mm in the U-tube group, respectively. No significant differences in accuracy were observed when comparing these two registration techniques.

Conclusion: Dynamic computer-assisted surgical systems can facilitate accurate implantation, and both the U-tube and cusp registration methods exhibit similar levels of accuracy. As the cusp registration technique can overcome some of the limitations of the U-tube strategy without the need for an additional registration device, it may be more convenient for clinical use and warrants further research.

KEYWORDS
accuracy, computer-assisted, dynamic navigation system, retrospective

What is known

Dynamic navigation is commonly employed in the context of implant surgery, and registration is essential to ensure the accuracy of navigation.

U-tube registration is among the most frequently utilized registration approaches as it is accurate, simple, and minimally invasive, but there are some limitations.

What this study adds

The retrospective study compared U-tube and cusp registration methods of dynamic navigation system in the context of dental implant placement assessed the accuracy of immediate implantation using dynamic navigation system.

Both the U-tube and cusp registration methods are highly accurate when implemented in vivo. The cusp registration technique can also overcome several of the limitations of the U-tube approach and it is more convenient for clinical use.

1 | INTRODUCTION

The three-dimensional (3D) position of dental implants is essential to the favorable outcomes of implant restoration, particularly with respect to aesthetic outcomes and long-term anterior tooth stability.[1,2] The development of digital implant navigation systems has enabled the more reliable evaluation of the 3D positioning of these implants.[3,4] These navigation systems consist of both static and dynamic systems. In static navigation systems, custom drilling guides are digitally designed and subsequently manufactured during preoperative planning. After that, the resultant guide plate can be placed onto the patient's jaw, mucosa, or teeth during surgery, with drilling subsequently being guided by metal sleeves prior to implant insertion.[5–7] In contrast, dynamic navigation system-based approaches rely on computer-mediated visualization of the jaw in volumetric computed tomography (CT) images, offering surgeons real-time screen-based guidance that can be used to complete the planned operation.[8]

Both static and dynamic navigation systems have higher accuracy than freehand implantation.[9–11] Compared to static navigation approaches, dynamic navigation systems exhibit several key advantages including: (1) more accurate implant site selection, decreasing operative complexity and improving safety[9]; (2) simpler operative procedures[12]; (3) the elimination of guide plate-related errors pertaining to the drill system or scanning technique,[13,14] together with a reduction in material costs and time associated with the guide plate preparation process; (4) reduced foreign body sensation associated with the guide plate, which also facilitating operator's field of vision; (5) the use of a universal implant system does not necessitate specialized drilling tools, and recent study demonstrated that the drilling protocol and utilized drilling devices can impact the accuracy of implant placement[13]; (6) the dynamic navigation approach is not constrained by the patient's mouth opening[6]; and (7) the technique is amenable to intraoperative adjustments to the operative plan.[15]

As dynamic navigation system-based approaches have become more widely implemented, there has been a growing focus on their relative accuracy. Both in vitro and in vivo studies have confirmed that dynamic navigation approaches have significant advantage on accuracy when compared to the free-hand implantation, while they are similar to the accuracy of static navigation systems when used for both single-tooth and two-implanted supported fixed dental prosthesis procedures.[10,16–18] Many factors can influence the accuracy of dynamic navigation, and appropriate registration between the planned and actual implants is essential in this operative context.[19] Registration is defined as the determination of spatial relationships between a preoperative virtual coordinate system and the intraoperative world coordinate system. Precise registration is vital to the success of dynamic navigation system-based implantation.[20] Following registration, the instrument tip can be monitored intraoperatively in real-time, displaying its position, path, and surrounding anatomical structures such that instrument positioning can be adjusted based on operator input.

There are two primary categories of registration methods: marker-based[21–24] and marker-free techniques.[25–28] Marker-based registration necessitates that markers be clear evident in preoperative images and readily detectable intraoperatively in patients. Such markers can include self-adhesive markers attached to the skin[29,30] a reference dental splint fitted to the teeth,[31] or bone-implanted screws.[32] In contrast, marker-free methods are based upon the craniofacial anatomy of a given patient. A common marker-free approach relies on the registration of prominent bony protrusions and corresponding structures such as the anterior nasal spine visible in CT bone scans.[33] Laser surface scanning is a specialized marker-free registration technique that matches random points on the surface of a tissue with corresponding points in CT scans.[26,34,35]

A U-tube is a small occlusal splint that leverages a tooth-supported reference plate. U-tube registration is a widely used registration technique that is minimally invasive, accurate, and straightforward.[20–24] However, this U-tube approach has certain limitations including a need for it to occupy a portion of the dentition space, the potential for it to affect fixed device positioning, difficulty ensuring accurate positioning, and the ease of deformation during long-term storage. In contrast, cusp registration is a marker-free approach that relies on the cusp or the fossa of teeth in the same jaw

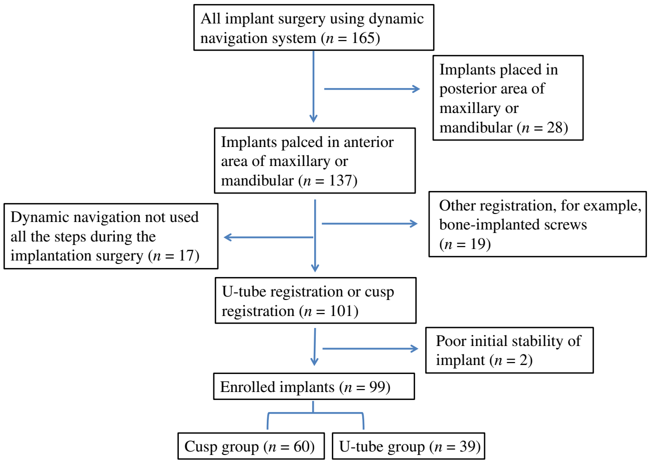

FIGURE 1 Workflow of patients' enrollment

as the missing teeth. Cusp registration does not necessitate the use of any additional physical devices and is not disturbed by the soft tissue, thereby overcoming certain U-tube registration-related shortcomings. However, no studies to date have compared the relative accuracy of these two registration techniques.

The present retrospective study was developed to compare the accuracy of these two different dynamic navigation system registration approaches in the context of in vivo anterior dental implantation. The secondary purpose of this study was to estimate whether the immediate implantation affect the accuracy of dynamic navigation implantation.

2 | MATERIALS AND METHODS

2.1 | Study design and ethical approval

A retrospective analysis of medical records from patients that had undergone dynamic navigation implant surgery between August 2019 and October 2020 at the First Clinical Division of Peking University Hospital of Stomatology was conducted. A total of 104 patients underwent the placement of 165 implants over the study period using a dynamic navigation system (DHC-D12, Suzhou Digital-health care Co., Ltd.®, Suzhou, China) and were enrolled in this study (Figure 1). After implantation, postoperative cone-beam computed tomography (CBCT) scanning was performed conducted to assess entry point and apex deviations as well as angle discrepancies between planned and actual implants. In addition, patients' clinical characteristics and radiographic findings were assessed.

This study was conducted in accordance with the Helsinki Declaration for biomedical research involving human subjects, and all patients agreed to participate after being informed regarding the study and its goals. The Institutional Review Boards of the Peking University School and Hospital of Stomatology (Approval Number: PKUSSIRB-202165090) approved this study. The study complied with the STORE checklist.

2.2 | Patient selection criteria

Patients eligible for inclusion were those meeting the following criteria: (1) patients with implants placed using a dynamic navigation system; (2) patients with implants placed in the anterior maxillary or mandibular regions; and (3) the implant placement was conducted via a U-tube or cusp registration approach.

Patients were excluded from this study if they exhibited poor initial implant stability or if dynamic navigation was not used during all steps of implant placement for any reason.

2.3 | Treatment history

2.3.1 | Preoperative preparation

Preoperative CBCT scans were performed for all patients (Crestream 9300, Crestream Health, France; 75 kV; 4 mA; field of vision: 10 * 10 cm; Slice thickness: 180 μm). In some patients in the U-tube registration cohort, silicone rubber (DMG Dental Products, Hamburg, Germany) was used to fix a U-tube with radiolabeled spots in the area of the missing teeth during CBCT imaging. In patients that underwent cusp registration, no additional devices were inserted during imaging. The resultant CBCT DICOM data were uploaded to the navigation system software (Dcarer® (DHC-D12, Suzhou Digital-health care Co., Ltd.®, Suzhou, China), and the planning features of this program were used to define the dental arch, inferior alveolar nerve path, and the position for each implant. All preoperative planning was performed by a single operator familiar with this software platform.

2.3.2 | Surgical procedures

The implant headpiece and the connecting line of the reference board (Figure 2A1) were matched using the Dcarer® system navigation device (DHC-D12, Suzhou Digital-health care Co., Ltd.®, Suzhou, China), and the dynamic navigator infrared receiver (optical camera; Figure 2A2) was positioned above the patient. Reference boards were then calibrated with software guidance (Figure 2A3), with the infrared connection being adjusted as appropriate. Reference boards were then fixed on the same dental arch using an appropriate splint and self-curing resin. The implant headpiece with the optical device, the reference board, and the infrared receiver were arranged such that they remained in a straight, unobstructed path (Figure 2A). Cusp or U-tube registration was then performed. In patients in the U-tube registration cohort, the U-tube (DHC-D12, Suzhou Digital-health care Co., Ltd.®, Suzhou, China) worn during preoperative CBCT imaging was worn again (Figure 3A,B), with the navigation implant headpiece being utilized to click the pit on the U-tube with the drill (Figure 3C,D). Six pits were selected for registration purposes. For patients undergoing cusp registration, six cusps or fossae of teeth in the same jaw as the missing teeth were utilized in lieu of the pits used for cusp registration (Figure 4A,B). Through the calculation of the positional distance from

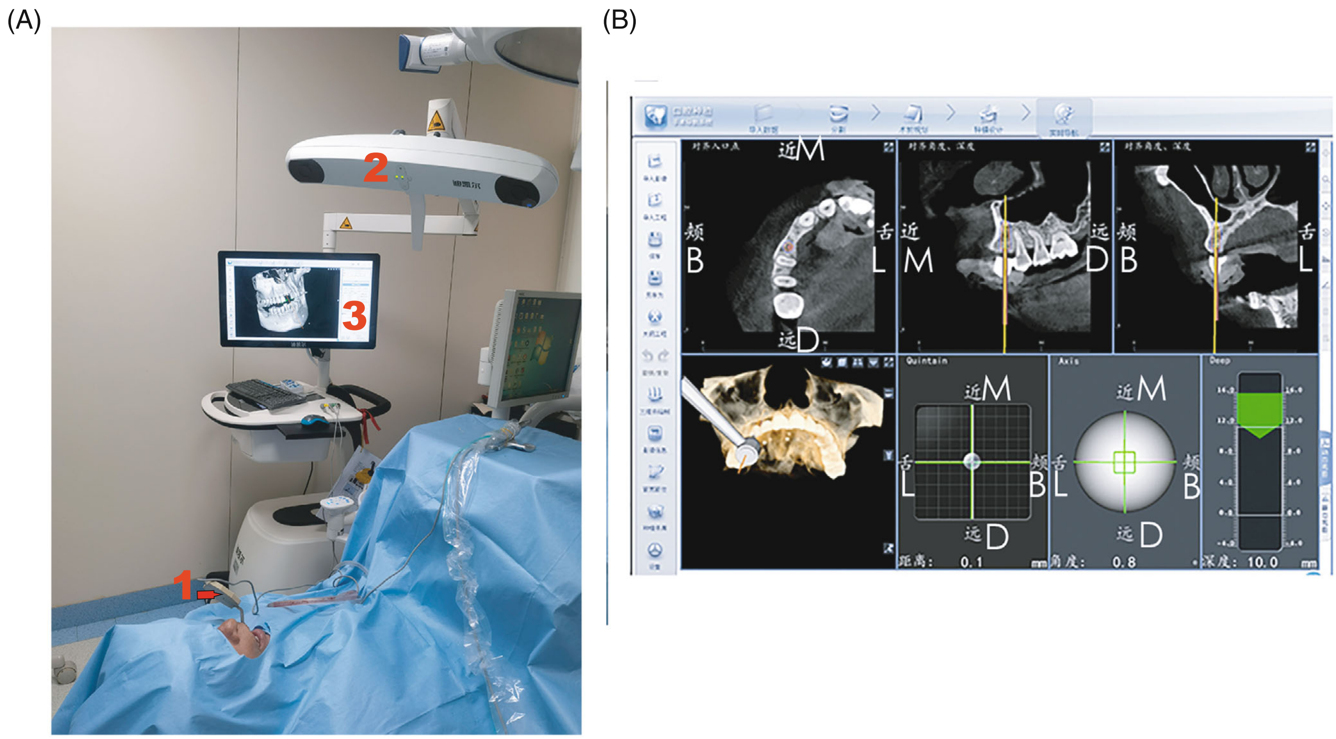

FIGURE 2 The dynamic navigation system. (A) Dcarer® work diagram: 1—infrared receiver (optical camera); 2—reference board; and 3—software interface. (B) Dcarer® software interface during surgical procedures

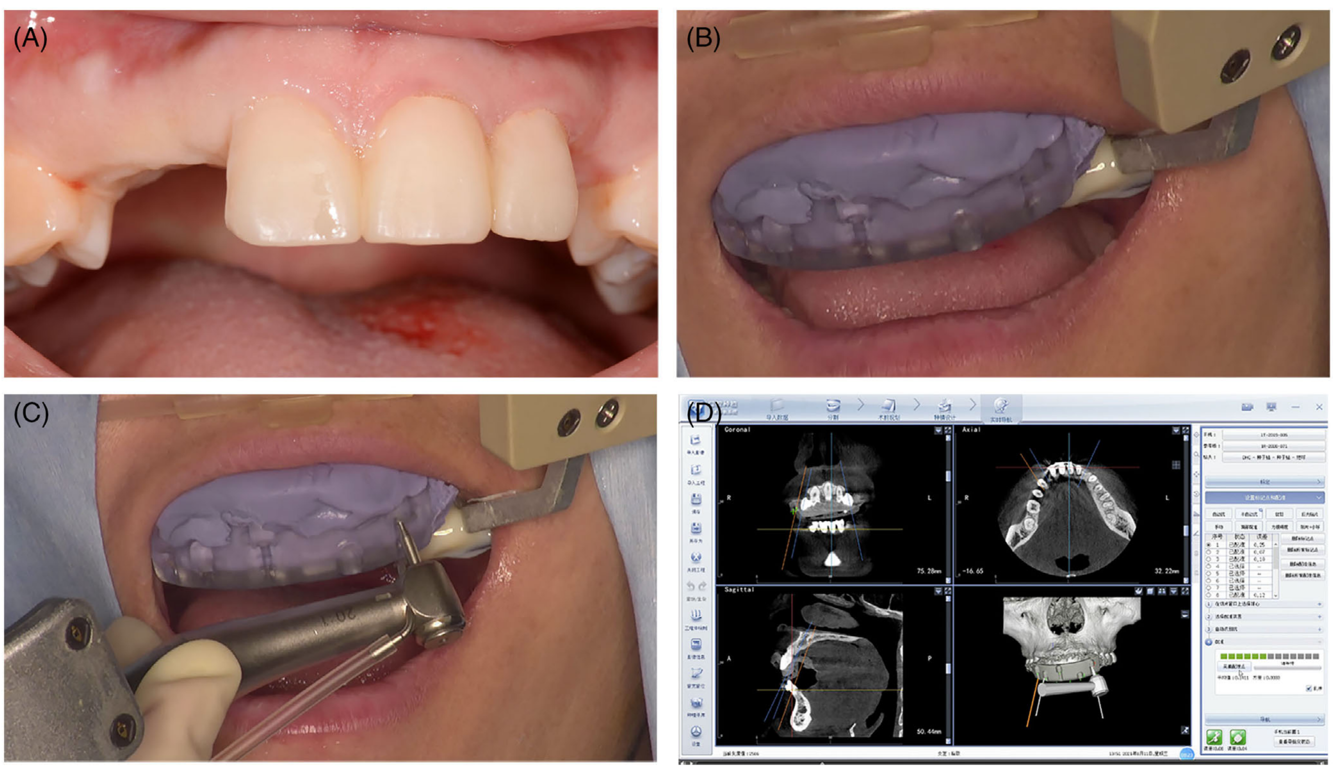

FIGURE 3 The process of U-tube registration. (A) before operation; (B) U-tube fixed in oral; (C) U-tube registration in oral; and (D) U-tube registration in software

the reference point, point-to-point registration was then performed to ensure appropriate identification and location of the operative area (Figure 4C,D).

All surgical procedures were conducted under local anesthesia, with a crestal incision being made using a type 15# scalpel blade. A soft tissue flap was then formed using an elevator, and drill axis and tip calibration were performed before drilling was initiated. Implant placement was performed based upon the recommended drilling protocol. The dynamic navigation system was used from the start of point fixing to the completion of the implant placement procedures (Figure 2B). All surgeries were performed by two surgeons with more than 10 years of surgical experience and more than 3 years of experience using navigation.

2.3.3 | Postoperative management

Postoperatively, patients immediately underwent CBCT imaging. Postoperative treatment for all patients was as follows: cefuroxime axetil (0.25 g bid per o.p.) or roxithromycin (0.15 g bid per o.p.) for 3–5 days together with daily mouth rinses with 0.2% chlorhexidine for 7 days.

2.4 | Data collection

SPSS 23.0 (IBM, New York, NY) was used to compile implant-related factors (implant diameter and length), site-related factors (tooth position, implant jaw location [maxilla or mandible]), and patient clinical factors (sex, age, general health, and behavioral history).

2.5 | Accuracy evaluation

An independent researcher overlaid preoperative and postoperative CBCT images for all patients with the Dcarer® dynamic

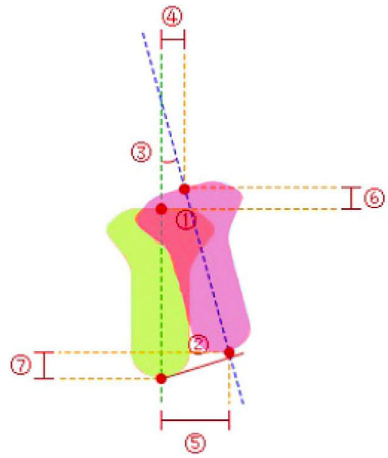

FIGURE 5 The measurement methods of the deviations between the planed and inserted implants. 1 entry deviation (3D deviation in the coronal aspect of the alveolar ridge); 2 apex deviation (3D deviation in the apical area of the implant); 3 angular deviation; 4 entry horizontal deviation; 5 apex horizontal deviation; 6 entry depth deviation; and 7 apex depth deviation

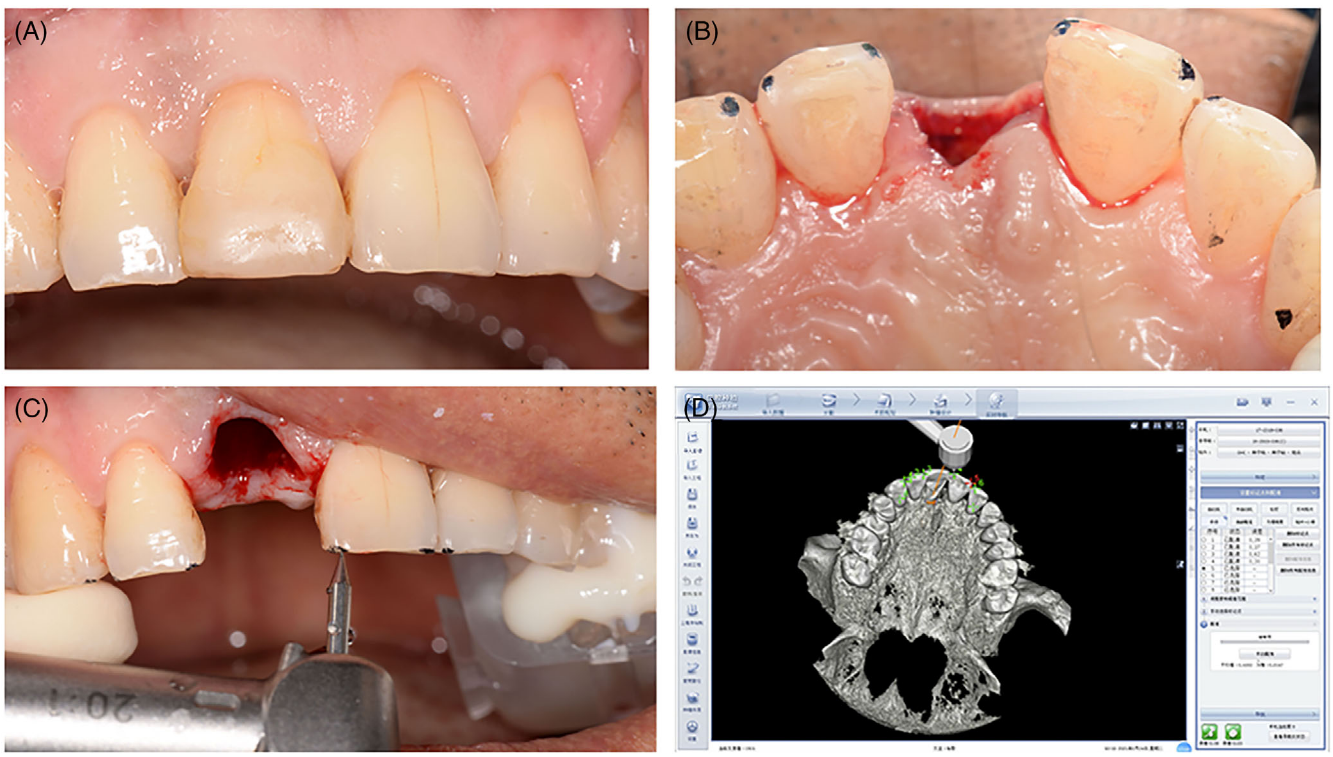

FIGURE 4 The process of cusp registration. (A) before operation; (B) the cusp (or fossa) chosen near operation area; (C) cusp registration in oral; and (D) cusp registration in software

navigation accuracy verification software (DHC-D12, Suzhou Digital-health care Co., Ltd.®, Suzhou, China), allowing for comparisons between planned and actual dental implant positions. For individual implants, variables compared between preoperative plans and final implant positions included the following (Figure 5): angular deviation, 3D deviation at the entry point (the alveolar ridge coronal aspect), 3D deviation at the apex deviation (in the implant apical area), 2-dimensional (2D) horizontal deviation of the entry point and apex point, and the deviation of entry point depth and apex point depth.

TABLE 1 Demographic and clinical characteristics of the included patients

	Cusp group	U-tube group	*p* value
Age			
Median (range)	46 (18–63)	51 (26–76)	
Mean ± SD	44.52 ± 12.70	48.13 ± 13.03	0.277
Gender			
Male	15	13	
Female	17	19	
Total number of implants	60	39	
Implant position			
Maxillary			
Middle incisor	22	16	
Lateral incisor	15	10	
Canine	4	5	
Mandible			
Middle incisor	7	3	
Lateral incisor	10	4	
Canine	2	1	
Implantation timing			
Immediate	10	8	
Delayed	50	31	

Note: No significant difference was observed ($p > 0.05$).

2.6 | Statistical analysis

A researcher blinded to patient grouping recorded and analyzed all data using SPSS 23.0 (IBM, NY). Data are given as means ± SD, and the Shapiro–Wilk test was used to assess the normality of data distributions. Data were compared between groups using Student's *t*-test or Mann–Whitney *U*-test as appropriate, with $p < 0.05$ as the threshold of statistical significance.

3 | RESULTS

Between 2019 and 2020, 104 patients underwent implant surgery using a dynamic navigation system-based approach in the First Clinical Division of the Peking University Hospital of Stomatology, with 165 total implants having been placed in these patients. Based upon study inclusion and exclusion criteria, 64 patients (28 males and 36 females; average age: 46.3 ± 12.9 years; range: 18–76), and 99 implants were included in the final study. The overall implant restoration survival rate was 100%, and no mechanical or biological complications were reported. The implantation success rate was 100%. Further details regarding patient demographics and implant sites are displayed on Table 1.

Deviation values associated with different registration methods are shown in Table 2. Angular deviation for the overall study cohort was 3.29 ± 0.17°, while in the cusp and U-tube groups these respective values were 3.25 ± 1.58° and 3.35 ± 1.78°. In the overall cohort, the 3D deviation was 1.29 ± 0.07 mm at the entry point and 1.43 ± 0.08 mm at the apex point, while in the cusp group these respective values were 1.28 ± 0.60 mm, and 1.34 ± 0.63 mm, and in the U-tube group, they were 1.30 ± 0.78 mm and 1.55 ± 0.90 mm. The 2D horizontal deviation for the overall cohort was 0.86 ± 0.50 mm at the entry point and 1.01 ± 0.60 mm at apex point, while in the cusp group these respective values were 0.89 ± 0.49 mm and 0.99 ± 0.52 mm, and 0.81 ± 0.51 mm and 1.06 ± 0.71 mm in the U-tube group. The deviation of entry point depth in the overall cohort was 0.82 ± 0.69 mm, with an apex depth of 0.85 ± 0.71 mm. These respective values were 0.78 ± 0.61 mm and 0.81 ± 0.62 mm in the cusp group, and 0.86 ± 0.80 mm and 0.91 ± 0.83 mm in the U-tube group. None of these values differed

TABLE 2 Difference between the different registration methods

	All enrolled	Cusp	U-tube	*p* value
Angular deviation (°)	3.29 ± 0.17	3.25 ± 1.58	3.35 ± 1.78	0.799
Entry deviation (mm)	1.29 ± 0.07	1.28 ± 0.60	1.30 ± 0.78	0.652
Apex deviation (mm)	1.43 ± 0.08	1.34 ± 0.63	1.55 ± 0.90	0.392
EH (mm)	0.86 ± 0.50	0.89 ± 0.49	0.81 ± 0.51	0.332
AH (mm)	1.01 ± 0.60	0.99 ± 0.52	1.06 ± 0.71	0.996
ED (mm)	0.82 ± 0.69	0.78 ± 0.61	0.86 ± 0.80	0.889
AD (mm)	0.85 ± 0.71	0.81 ± 0.62	0.91 ± 0.83	0.989

Note: No significant difference was observed ($p > 0.05$).
Abbreviations: AD, apex depth; AH, apex horizontal; ED, entry depth; EH, entry horizontal.

TABLE 3 Distribution of buccal-lingual and mesial-distal directions of the implants

			BD	BM	LD	LM
Entry	Cusp	No.	25	23	7	5
		Value (mm)	0.92 ± 0.50	0.96 ± 0.52	0.54 ± 0.31	0.86 ± 0.44
	U-tube	No.	8	16	10	5
		Value (mm)	0.91 ± 0.80	0.77 ± 0.40	0.74 ± 0.47	0.90 ± 0.44
Apex	Cusp	No.	17	17	11	15
		Value (mm)	1.18 ± 0.6	0.96 ± 0.50	0.98 ± 0.60	0.80 ± 0.38
	U-tube	No.	4	16	12	7
		Value (mm)	0.50 ± 0.22	1.16 ± 0.82	0.93 ± 0.60	1.05 ± 0.71

Abbreviations: BD, buccal-distal; BM, buccal-mesial; LD, lingual-distal; LM, lingual-mesial.

TABLE 4 Difference between the immediate implant and delayed implant

	Immediate implant	Delayed implant	*p* value
Numbers	18	81	
Angular deviation (°)	3.42 ± 1.74	3.26 ± 1.84	0.835
Entry deviation (mm)	1.06 ± 0.46	1.33 ± 0.08	0.112
Apex deviation (mm)	1.04 ± 0.56	1.51 ± 1.34	0.011*
EH (mm)	0.80 ± 0.58	0.87 ± 0.77	0.35
AH (mm)	0.81 ± 0.43	1.06 ± 0.80	0.463
ED (mm)	0.58 ± 0.55	0.87 ± 0.80	0.209
AD (mm)	0.59 ± 0.54	0.90 ± 0.91	0.068

Note: No significant difference was observed (p >0.05).
*p <0.05.

significantly between groups. Table 3 shows the distribution of buccal-lingual and mesial-distal implant directions in different groups.

Differences between immediate implant or delayed single-tooth implants are shown in Table 4. There were no significant deviations for any of the measured indicators except the 3D apex deviation when considering whether to place an implant in the extraction socket.

4 | DISCUSSION

Dynamic navigation system approaches are widely used in the context of dental implant placement, and several studies to date have found these computer-aided systems to be associated with reductions in the incidence of drilling-related sinus perforation and inferior alveolar nerve injury. DNS-assisted implant placement has been shown to be more accurate and reproducible than the conventional freehand method and similar to template-based static guidance.[10,16,36–38] A recent meta-analysis reported that in the dynamic navigation system group, the pooled weighted mean angular deviation was 3.807°, while the pooled weighted mean 3D deviation was 1.090 mm at the entry point and 1.305 mm at the apical point. These results were lower than the freehand group, with a pooled weighted mean difference in angular deviation of −4.468°, a 3D coronal deviation of −0.444 mm, and a 3D apical deviation of −0.857 mm. Relative to the static technique, the difference between the two groups was not significance in any of these deviation variables.[37]

Some prior studies have compared the accuracy of different dynamic navigation system brands or techniques conducted in different nations, assessing deviations between planned and actual entry points, apex points, and angle values as a means of defining the relative accuracy of these approaches and tools.[7,9,39,40] Herein, we measured angular deviation, entry deviation, and apex deviation values of 3.29 ± 0.17°, 1.29 ± 0.07 mm, and 1.43 ± 0.08 mm, respectively, in line with the results in previously published reports.[41,42]

The accuracy of computer-based dynamic intraoperative navigation is dependent upon a range of factors, including CT resolution, preoperative planning, registration precision, tracking system precision, and the positioning, number, and the type of fiducial markers used. It is critical to ensure the accuracy of each step to avoid the accumulation of multiple errors. Low CBCT quality/resolution, the mismatch of the radiological fiducial markers (which are usually tooth-supported), movements of the fiducial marks or of the patient during CBCT imaging, or problems during registration of the radiological markers with the planning software are all potential sources of inaccuracy. Intraoperatively, other potential sources of error may include the movement of optical markers placed on the patient's jaw or on the handpiece or the incorrect calibration or imprecise manipulation of the drill. In addition, postoperative assessment errors can affect study results.[43] Registration method selection and position can also profoundly impact navigation accuracy, intraoperative navigation time, and overall operative difficulty.[17]

Herein, we conducted a retrospective analysis of 64 patients and 99 implants in order to compare the accuracy of two different dynamic navigation system registration techniques. No differences were observed between the U-tube and cusp registration groups. The U-tube registration technique is accurate and frequently used in the context of dynamic navigation system-based approaches. However, in the clinic, several potential issues must be taken into consideration. For one, the installation of removable dental splints is sometimes overlooked before CT scanning.[44] Secondly, incorrect placement or loosening of the splint either during imaging or during subsequent registration can result in unforeseen errors.[45] Poor tooth stability can cause imprecision even with a well-fitted splint. In contrast, cusp registration is based on anatomical landmarks much like bone mark registration when teeth are stable. As such, cusp registration does not necessitate the use of an additional registration device and is not impacted by the edentulous area. However, further research regarding the details of the cusp registration procedure is warranted, and operator experience may be an important determinant of patient outcomes.[9,40,46] In addition, the quality and definition of CBCT images can have a major impact on registration. If there are too many metal restorations in the same jaw of missing teeth, cusp registration is generally not a good choice. Additional study of the strengths and limitations of this approach is thus important in order to optimize the overall feasibility and accuracy of this procedure.

We also examined the effects of immediate and delayed implantation on overall operative accuracy. A recent article demonstrated that high accuracy and primary stability for immediate implant placement could be achieved using both tapered and straight implants when employing dynamic navigation systems.[47] Locating and maintaining the direction of the extraction socket may prove challenging in this context. However, no differences were detected between immediate and delayed implantation in this study, suggesting that the different timing of implantation may be comparable when using a dynamic navigation system-based approach.

While the results of our study indicated that both of the two tested registration approaches were reliable, this was a small-scale retrospective study. Further large-scale clinical analyses with an improved study design will thus be necessary to validate and expand upon our findings.

5 | CONCLUSIONS

Dynamic computer-aided surgery approaches offer a valuable and reliable means of improving dental implantation accuracy. The results of this study suggest that both the U-tube and cusp registration techniques can achieve high levels of accuracy in vivo in a clinical setting. Notably, the cusp registration technique is both feasible and not subject to some of the limitations of the U-tube approach as it obviates the need for additional registration devices and is more convenient, making it a viable technique worthy of additional clinical research.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Feifei Ma: design, data collection, drafting article, and approval of article. **Feng Sun:** design, critical revision of article, approval of article, and funding secured by. **Tai Wei:** data analysis, statistics analysis, critical revision of article, and approval of article. **Yu Ma:** preoperative planning use the software.

DATA AVAILABILITY STATEMENT

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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