Analysis of the accuracy of a dynamic navigation system when performing dental implant surgery with transcrestal sinus floor elevation using a piezoelectric technique: a retrospective study

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Research article

Keywords: Dynamic navigation, transcrestal sinus floor elevation, Accuracy, piezoelectric, implant surgery

Posted Date: February 15th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-936614/v1

Abstract

Background To evaluate the accuracy associated with the use of a dynamic navigation system when conducting posterior maxilla implant surgery with transcrestal sinus floor elevation (TSFE) a piezoelectric technique.

Methods In total, 28 implants were placed in 28 patients requiring implantation in the posterior maxilla via a TSFE approach. A drill was used to access the planned position (within 1 mm of the bottom of the maxillary sinus floor) under dynamic navigation system guidance. TSFE was then accomplished using osteotomes and a piezoelectric device. Three effective deviations between planned and actual implant placement were then measured including angular deviation (AD, degrees), entry point horizontal deviation (EPHD, mm), and apical point horizontal deviation (APHD, mm).

Results The AD, EPHD, and APHD between the planned and actual implant placement were 3.656±1.665 degrees, 1.073±0.686 mm, and 1.086±0.667 mm, respectively. Premolar site AD values were less than those for molar sites ($P=0.004$). No significant differences in these outcomes were observed when comparing procedures conducted by two different surgeons. Obvious sinus perforation was not detected by immediate postoperative cone-beam computed tomography imaging.

Conclusions The accuracy associated with using a dynamic navigation system when conducting posterior maxilla implant surgery via a TSFE approach using piezoelectric devices was comparable to that observed for previously published conventional implant navigation approaches. This technique thus achieved appropriate interventional precision and safety while decreasing the morbidity associated with the TSFE approach.

Background

Transcrestal sinus floor elevation (TSFE) is a commonly used operative technique in the posterior maxilla when there is insufficient residual bone height. Several studies have demonstrated that this approach is less invasive, associated with fewer complications, and requires a shorter operative duration as compared to other techniques [1]. The success of TFSE, however, is primarily reliant upon the experience of the operating surgeon owing to the limited operative visibility associated with this surgical approach. When using drills and hand osteotomes, Schneiderian membrane perforations have the potential to occur, and detecting such perforations during or after TSFE procedures remains challenging. As such, the development of effective preventative approaches and devices is important in order to ensure better patient outcomes. Notably, these Schneiderian membrane perforations may be avoidable when applying a dynamic navigation system and piezoelectric devices in this operative context.

Dynamic computer-aided implant surgery (dCAIS) has been proposed as an effective approach to minimizing intraoperative deviation from planned implant placement [2, 3], enabling the safe and accurate location of an entry point in the surgical area while facilitating the avoidance of the maxillary sinus and inferior alveolar nerve [4, 5], thus ensuring dynamic mastery over the operative space and the angle of implant placement [6, 7]. Such dynamic navigation systems provide real-time 3D visuals during implant surgery, ensuring the consistent tracking of implant drills and the location of the maxillary sinus floor.

Piezoelectric devices use ultrasonic microvibrations to perform an osteotomy without cutting the soft tissue, thereby largely avoiding any harm to the sinus mucosa. Piezoelectric device use in the context of TSFE has been reported to reduce membrane perforation and to yield satisfactory results [8, 9].

In our clinical experience, the combined use of a dynamic navigation system and piezoelectric devices can accurately and safely remove the bone at the bottom of the maxillary sinus floor when performing implant surgery with TSFE. Several studies have confirmed the efficacy and accuracy of utilizing a dynamic navigation system when conducting implant placement [10-12]. However, no prior studies to our knowledge have explored the accuracy of such a system in the context of posterior maxilla implant surgery conducted via a TSFE approach and using piezoelectric devices. As such, we herein sought to assess the angular deviation, entry point horizontal deviation, and apical point horizontal deviation in this surgical context in order to better establish the accuracy of this technique and to evaluate its relative advantages and the factors which may influence associated outcomes.

Methods

Patient selection

This retrospective analysis was approved by the Institutional Ethics Committee of our hospital. Between October 2019 and July 2021, 28 total implants (SP, φ 4.1 or 4.8 mm, SLActive® 8 or 10 mm, Roxolid®, Loxim®, Straumann, Switzerland) were placed in 28 patients requiring implantation in the posterior maxilla with TSFE. Digital visual planning was performed for all implants, which were placed using dynamic navigation system guidance.

Patients eligible for inclusion in this study were: (1) individuals requiring posterior maxillary implants; (2) individuals that had provided written informed consent for the use of a dynamic navigation system; (3) individuals for whom preoperative digital visual implant planning was conducted; (4) patients that underwent simultaneous TSFE; and (5) patients with good overall health who were able to accept the risks associated with implant surgery. Patients were excluded from this study if they exhibited: (1) a limited ability to open their mouth; (2) an excessive gag reflex; (3) irradiation of the maxilla; (4) poor oral health; (5) a history of heavy smoking; (6) bisphosphonate treatment; (7) uncontrolled diabetes; (8) a history of drug use; or (9) other conditions with the potential to impact the implant surgery procedure or the use of a dynamic navigation system.

Preoperative preparation

Cone-beam computed tomography (CBCT) scans were acquired for all patients using identical settings (90 kV, 8 mA, 8 s, voxel size: 180 μm; Crestream 9300, Crestream Health, France). All patients had a silicone elastomer registration device placed in the surgical site prior to CBCT imaging (Fig. 1a). Navigation registration requires that there be one-to-one corresponding marker points (the developing ball on the registration device) in the mouth and on the CBCT scans. This registration device was soaked in alcohol for 30 min prior to implant surgery. Digital CBCT data were imported into the dental implant dynamic navigation system software (Dcarer®), which was used to conduct preoperative implant planning. For each implant, the optimal implant platform diameter, apical diameter, and length were selected from the system implant library, and a suitable 3D virtual implant position was selected. As the implants in our patients were placed in the posterior maxilla with TSFE, the preoperative planned implant apical position was within 1 mm or less of the bottom of the maxillary sinus floor (Fig. 1b). All preoperative virtual implant planning was conducted by a single surgeon with five years of experience in performing computer-aided implant surgery and 10 years of experience in conventional implant surgery.

All patients underwent ultrasonic scaling approximately one week before implant surgery was performed. A prophylactic protocol was conducted (cefuroxime axetil [0.25 g per os] or roxithromycin [0.15 g per os] 30 min prior to surgery). Prior to entering the operating room, patients were required to rinse their mouth with a 0.2% chlorhexidine solution for 60 s.

Surgical procedure

First, calibration is performed for instruments with a required handpiece locator and reference device. Both of these surfaces have infrared light transmitters, which actively send infrared light that is received as a signal by the navigator to establish the spatial position of the device. A long ball drill and a short ball drill are installed on the handpiece in turn (with these two drills being used because the endpoints of the two drilling needles establish an axis that is used when determining the orientation of the handpiece). The spherical portion of the drilling needle is positioned proximal to the hemispherical groove specified on the reference device (Fig. 1c). In this state, the navigator collects the signals sent by the handpiece locator and the reference device to determine the relative positional relationship between them. The second step is registration, in which the reference device with the fixation device was placed on the other side of the same jaw such that the spatial position of the reference device represents the position of the patient's jaw. The actual registration device is reset in the mouth, and the virtual CBCT resets the same virtual registration device. A short ball drill is installed on the handpiece to collect the specific ball pit information (at least six marker points) on the registration device (Fig. 1d, e), and the relative positional relationship of the handpiece locator, reference device, virtual CBCT, and jaw position can then be determined after collection. The registration device is then removed, and the drill is placed on the cusp of the tooth to determine whether the drill position displayed in the dynamic navigation system is accurate (Fig. 1f). The surgeon is then able to obtain a real-time 3D visualization of the drill and implant during surgery, enabling them to monitor the preoperatively planned implant position and the anatomic structures around the maxillary sinus floor (Fig. 1g).

After the registration process, a midcrestal incision with a full-thickness flap is made, and the drill is operated under the guidance of the dynamic navigation system to reach the planned site on the bottom of the maxillary sinus floor (Fig. 1h). A piezoelectric device and osteotomes are then used to accomplish

TSFE (Fig. 1i-k). A dome-shaped elevator is used after the piezoelectric surgery and prior to osteotome use for premolars with a mesiodistal maxillary sinus sloping floor and for molars with a buccolingual sloping maxillary sinus floor. Lastly, the implant is inserted into the surgical site under the direct view of the dynamic navigation system (Fig. 1l, m) (Model: DHC-DI2, Suzhou Digital-health care Co., Ltd.).

Postoperative treatment

After surgery, patients underwent immediate CBCT imaging (Fig. 1n). The postoperative protocol treatment protocol for all patients was as follows: cefuroxime axetil (0.25 g bid per os) or roxithromycin (0.15g bid per os) for 3–5 days with daily mouth rinses with 0.2% chlorhexidine for 7 days. Sutures were generally removed within 7 days after surgery.

Accuracy evaluation

The planned preoperative and actual postoperative positions of the implants were matched by a blinded expert using the Dcarer® dynamic navigation accuracy verification software to measure deviations between the two. Owing to the specific position of these implants in the posterior maxilla with TSFE in our patients, we measured three effective deviations between these two positions, including angular deviation (AD, degrees), entry point horizontal deviation (EPHD, mm), and apical point horizontal deviation (APHD, mm) (Fig. 2).

Deviation Definition

AD: The angle between the center axes of the planned and actual implants.

EPHD: The difference in the horizontal plane (mesiodistal and buccolingual placement) between the entry point of the planned and actual implants.

APHD: The difference in the horizontal plane (mesiodistal and buccolingual placement) between the apical point of the planned and actual implants.

Statistical analysis

Deviations at different sites and among different surgeons were analyzed using independent-samples t-tests. Analyzed outcome variables included AD (degrees), EPHD (mm), and APHD (mm). SPSS 24.0 was used for all statistical testing.

Results

Patient demographic and clinical characteristics

A total of 28 implant procedures (12 premolars, 16 molars) were performed in 28 patients (15 male, 13 female), with a mean patient age of 50 years (range: 29–78). In total, there were 28 maxillary implant sites with 5–9 mm of residual bone height.

Complications

Intraoperative adjustments were made to planned implant positioning for two implants in this study. We strictly and carefully selected the indications for TSFE, and the lifting height was controlled at 2–4 mm. Immediate postoperative CBCT did not reveal any significant maxillary sinus perforation (fluid plane or scattered bone graft material). All patients exhibited routine responses including mild swelling and/or pain which recovered within 1 week after implant surgery with TSFE performed using dynamic navigation and piezoelectric devices. No incision site infections or symptoms of sinusitis were detected.

Implant placement accuracy

We measured three effective deviations between planned and actual implant positions, including AD (degrees), EPHD (mm), and APHD (mm). These three values were 3.656 ± 1.665 degrees, 1.073 ± 0.686 mm, and 1.086 ± 0.667 mm, respectively (Table 1).

Table 1
Dynamic navigation system accuracy in the context of implant surgery with TSFE using piezoelectric technique

	AD (°)	EPHD (mm)	APHD (mm)
Mean ± SD	3.656 ± 1.665	1.073 ± 0.686	1.086 ± 0.667
Min-max	0.791–6.487	0.031–2.682	0.233–2.782
95% CI	3.011–4.302	0.807–1.339	0.828–1.345

Accuracy comparison between premolar and molar sites

We next compared the relative accuracy of implant placement via this approach between premolar and molar sites. AD values for premolar sites were lower than for molar sites ($P = 0.004$), whereas there were no significant differences between premolar and molar sites with respect to EPHD or APHD (Table 2).

Table 2
The AD, EPHD, and APHD of different implant sites

Sites	number	AD (°)	EPHD (mm)	APHD (mm)
premolar	12	2.666 ± 1.123	0.832 ± 0.684	0.945 ± 0.766
molar	16	4.399 ± 1.640	1.254 ± 0.650	1.192 ± 0.585
P		0.004	0.108	0.342

Accuracy comparison between surgeons

We additionally compared the accuracy outcomes associated with this approach between the two surgeons who performed these implant procedures, one of whom had five years of experience and the other of whom had > 10 years of experience in conventional implant placement. We did not detect any significant differences in AD, APHD, or EPHD between surgeons (Table 3).

Table 3
The AD, EPHD, and APHD of different surgeons

Surgeon	number	AD (°)	EPHD (mm)	APHD (mm)
Surgeon 1	16	3.598 ± 1.648	0.903 ± 0.599	0.998 ± 0.490
Surgeon 2	12	3.735 ± 1.757	1.300 ± 0.754	1.205 ± 0.859
P		0.834	0.132	0.465

Discussion

Several prior studies have compared the accuracy of navigation systems, static guide surgery, and freehand surgery *in vitro* [2, 13], with navigation systems yielding comparable or superior accuracy relative to static guide surgery and superior accuracy to that associated with freehand dental implant surgery. Similar findings have also been reported in clinical practice [14–16]. Dynamic navigation is thus a reliable clinical approach [17], the accuracy of which is not affected by surgeon experience level [15, 16].

TSFE was first introduced in the 1980s and was later modified by Summers [18], who introduced a technique in which a conventional drill was used to reach approximately 2 mm below the maxillary sinus floor. Hand osteotomes were then used to elevate the Schneiderian membrane after the infracture of the sinus floor [19]. The residual bone height of 5–9 mm achieved good postoperative outcomes and minimal complications [20, 21]. The piezoelectric internal sinus elevation (PISE) technique was introduced in 2003 [22], and relies upon the use of a piezoelectric surgical tip in place of osteotomes. However, bone graft condensation is still required to elevate the sinus membrane in this procedure. For the present study, we used a drill to reach the planned position (within 1 mm of the bottom of the maxillary sinus floor) under the guidance of the dynamic navigation system. Then, a piezoelectric surgical tip was used to break through the sinus floor. After penetrating the sinus floor, osteotomes were inserted to elevate the sinus mucosa. Following membrane elevation, the graft was compacted into the osteotomy site and the implant was placed. Through the application of a piezoelectric device during this procedure, the duration and magnitude of osteotome use were dramatically reduced. Significant maxillary sinus perforation in this operative context may be avoided as evidenced by the immediate postoperative CBCT images.

In a recent systematic review of the accuracy of dynamic computer-aided implant placement conducted by Jorba-García et al. [2], the authors reported an average angular deviation of 3.68 degrees (95% CI: 3.61 to 3.74), an average coronal global deviation of 1.03 mm (95% CI: 1.01 to 1.04), an average apical global deviation of 1.34 mm (95% CI: 1.32 to 1.36) mm, an average lateral (2D) entry of 0.69 mm (95% CI: 0.67 to 0.72), and an average lateral (2D) apex of 0.9 mm (95% CI: 0.83 to 0.97) in clinical studies. Aydemir and Arısan [6] conducted dynamic navigation and freehand patient implant placement in the posterior maxilla, and measured an average coronal deviation of 1.01 mm (*SD*: 0.07 mm), an average apical deviation of 1.83 mm (*SD*: 0.12 mm), and an average angular deviation of 5.59 degrees (*SD*: 0.39 degrees) in the navigation group. In their study of 219 implants placed using a fully guided dynamic navigation approach, Block et al. [23] reported an average angular deviation of 2.97 degrees (*SD*: 2.09), an average coronal global deviation of 1.16 mm (*SD*: 0.59), an average apical global deviation of 1.29 mm (*SD*: 0.65), an average lateral (2D) entry of 0.74 mm (*SD*: 0.43), and an average lateral (2D) apex of 0.9 mm (*SD*: 0.55). Herein, we measured AD, EPHD, and APHD deviations between planned and actual implant placement, and found these values to be 3.656 ± 1.665 degrees, 1.073 ± 0.686 mm, and 1.086 ± 0.667 mm, respectively. Additionally, we found the angular deviation to be smaller for premolar sites relative to molar sites, and found that surgeon experience level had no impact on the overall accuracy of this approach.

Relative to dynamic navigation, the accuracy of freehand implant placement approaches is generally reported to be substantially reduced. For example, Block et al. [23] reported freehand placement to be associated with an average angular deviation of 6.5 degrees (*SD*: 4.21), an average coronal global deviation of 1.78 mm (*SD*: 0.77), an average apical global deviation of 2.27 mm (*SD*: 1.02), an average lateral (2D) entry of 1.19 mm (*SD*: 0.68), and an average lateral (2D) apex of 1.84 mm (*SD*: 1.05) when assessing 122 implants placed via a such an approach. Varga et al. [24] reported an average angular deviation of 7.13 degrees, an average coronal global deviation of 1.76 mm, and an average apical global deviation of 2.42 mm in the maxilla when conducting freehand surgery. Block reported that for 20 patients who underwent freehand surgical placement performed by two surgeons, mean angular deviation, platform lateral deviation, and apical lateral deviation values were 7.69 degrees, 1.15 mm, and 2.21 mm, respectively [16]. In a separate study comparing planned and actual implant placement in a mental navigation group, Vercruyssen et al. [25] reported an average coronal deviation of 2.77 mm (*SD*:1.54 mm), an average apical deviation of 2.91 mm (*SD*: 1.52 mm), and an average angular deviation of 9.92 degrees (*SD*: 6.01 degrees). Aydemir and Arısan [6] compared dynamic navigation and freehand approaches in patients with bilateral edentulism in the posterior maxilla in whom sufficient bone volume was available to insert a standard implant (3.5-mm diameter and 10-mm long), reporting an average coronal deviation of 1.70 mm (*SD*: 0.13 mm), an average apical deviation of 2.51 mm (*SD*: 0.21 mm), and an average angular deviation of 10.04 degrees (*SD*: 0.83 degrees) in the freehand group. These results thus suggest that freehand implant placement is less accurate as compared to computer-aided approaches. This is a particularly important consideration when operating on an anatomical site that requires absolute accuracy during the implant placement procedure.

Pozzi and Moy evaluated the placement of 136 implants in 66 patients using a computer-guided template to perform flapless transcrestal maxillary sinus floor elevation with an expanding-condensing osteotomes protocol. This approach was able to achieve high rates of implant success when implanting implants into the posterior maxilla in a site with a single missing tooth with sufficient bone height (5–9 mm) [26].

The conventional TSFE procedure was used to estimate the position of the drill based on the preoperative CBCT images, positioning it to 1 mm below the floor of the maxillary sinus [27]. For less experienced surgeons and even experienced surgeons dealing with the unique anatomical structure of the maxillary sinus, the actual direction and depth of the drill often differ from those planned positions. This can result in two outcomes. For one, this can cause damage to or perforation of the maxillary sinus mucosa. Second, it may result in the presence of more residual bone below the sinus floor than expected, affecting the subsequent use of hand osteotomes. If a piezoelectric device is used, however, it will prolong the operative duration. Dynamic navigation has noteworthy advantages when conducting posterior maxillary implant surgery with TSFE, particularly for premolars with a mesiodistal sloping maxillary sinus floor and for molars with a buccolingual sloping maxillary sinus floor (Fig. 3a, b). A dome-shaped elevator was used after piezoelectric surgery and before osteotome use for patients in whom such sloping was observed (Fig. 3c). The preoperatively planned apical implant position was 1 mm or less from the maxillary sinus floor, and we were able to use the visual dynamic navigation system to accurately drill to the lowest point of the sloping maxillary sinus floor. We then removed the bone upward along the lowest point of the maxillary sinus floor via piezoelectric osteotomy to achieve TSFE. We were then able to insert the traceable implant into the optimal position using the screen of the dynamic navigation system.

Several factors have the potential to impact the accuracy of dynamic navigation. CBCT image quality can be impacted by hardware, software, and human factors [3]. Preoperative and postoperative CBCT imaging should be conducted using the same settings, as differing CBCT images would impact the accuracy of overlap between planned and actual implant positions. Patients have a registration device placed in the surgical site using silicone elastomer prior to undergoing CBCT scanning. Registration device movement would result in the incorrect positioning of the radiological fiducial markers. As per manufacturer recommendations, it is necessary to return the device to the company for calibration after every 50 uses. When not checked and repaired in a timely fashion, the system will yield poor accuracy. Owing to a lack of teeth contour and poor periodontal conditions, unstable registration and fixing device positioning can also result in inaccurate dynamic navigation during surgery. Intraoperative factors can also contribute to overall accuracy. Surgeons face a learning curve to achieve proficiency with this approach [16]. The degree of mouth opening can also affect the maxillary posterior implant procedure, as it can confine the handpiece and drills to a limited area. During the TSFE operation, the density of residual bone and cortical bone at the base of the maxillary sinus can also impact operative accuracy. The nonuniform or discontinuous removal of bone from the floor of the maxillary sinus can result in inaccurate implant positioning, particularly for maxillary posterior sites with less residual bone height.

We have several suggestions that may aid others in their efforts to achieve optimal accuracy when conducting posterior maxillary implant surgery with TSFE using dynamic navigation. First, all patients should be fitted with a registration device using silicone elastomer in the implant site prior to CBCT imaging. The selection of the registration device type, placement, and finishing all warrant careful consideration. We were able to use a long registration device and additional silicone elastomer to extend the overall length of this device for patients in whom the free ends of the posterior teeth were missing. Patients can additionally bite rolled cotton on the registration during CBCT scanning. All of these steps can improve registration device stability and the repeatability of associated manipulation. During implant surgery, it is important to ensure the stability of the registration and fixation devices. We applied steady pressure to the registration device and selected evenly distributed registration points to complete the registration process. We were then able to perform infiltration anesthesia after registration, particularly in patients in whom the free ends of posterior teeth were missing, thereby avoiding the influence of soft tissue changes on registration accuracy. Stability during all stages of the implant placement procedure is critical, and the navigation guidance should be carefully followed, with the actual position of the implant in the surgical site being assessed to establish whether further modifications to the implant design are required. The implant should also be inserted under navigation guidance to ensure consistency between the planned and actual positioning of the implant.

Study limitations

As this was a retrospective study with a small sample size performed by two surgeons, additional large-scale prospective analyses will be essential to confirm the accuracy of dynamic navigation systems in the context of dental implant surgery with TSFE. Such future prospective randomized controlled trials should enroll surgeons with differing experience levels in order to gain further insight regarding the relationships among maxillary sinus anatomy, dentist seniority, and other variables associated with safe and accurate patient outcomes following implant surgery with TSFE.

Conclusions

In summary, the results of this study suggest that the accuracy of dynamic navigation systems used when conducting posterior maxilla implant surgery with TSFE using piezoelectric devices is similar to that of previously published conventional implant navigation techniques, improving the precision and safety of these interventions while decreasing the morbidity of TSFE, making it a suitable approach for clinical posterior maxilla implant placement. The angular deviation values for premolar sites were smaller than those for molar sites, and surgeon experience level did not have any impact on the accuracy of this navigation method.

Abbreviations

TSFE: Transcrestal sinus floor elevation; dCAIS: Dynamic computer-aided implant surgery; CBCT: Cone-beam computed tomography; AD: Angular deviation; EPHD: Entry point horizontal deviation; APHD: Apical point horizontal deviation.

Declarations

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of the Institutional Review Board of Peking University School and Hospital of Stomatology and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the Institutional Review Board of Peking University School and Hospital of Stomatology (PKUSSIRB-202165090). Written informed consent was not required for this study because we have indicated the contents of this study in the surgical consent. The application of the free informed consent was approved by the Institutional Review Board.

Consent for publication

Not applicable

Availability of data and material

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

Competing interests

Bin-Zhang Wu, Fei-Fei Ma and Feng Sun declare that they have no competing interests.

Funding

The study was not supported by any source of funding.

Authors' contribution

BZW and FS performed the dynamic navigation implant surgery. BZW and FFM analyzed and interpreted the patients data. All authors read and approved the final manuscript.

Acknowledgements

Not applicable

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References

1. Farina R, Franceschetti G, Travaglini D, Consolo U, Minenna L, Schincaglia GP, Riccardi O, Bandieri A, Maietti E, Trombelli L. Morbidity following transcrestal and lateral sinus floor elevation: A randomized trial. J Clin Periodontol. 2018;45(9):1128-39.
2. Jorba-García A, González-Barnadas A, Camps-Font O, Figueiredo R, Valmaseda-Castellón E. Accuracy assessment of dynamic computer-aided implant placement: a systematic review and meta-analysis. Clin Oral Investig. 2021;25(5):2479-94.
3. Wei SM, Zhu Y, Wei JX, Zhang CN, Shi JY, Lai HC. Accuracy of dynamic navigation in implant surgery: A systematic review and meta-analysis. Clin Oral Implants Res. 2021;32(4):383-93.
4. Chen YT, Chiu YW, Peng CY. Preservation of Inferior Alveolar Nerve Using the Dynamic Dental Implant Navigation System. J Oral Maxillofac Surg. 2020;78(5):678-9.
5. Yao Y, Lin Z, Yang X. Implant placement in the pterygoid region with dynamically navigated surgery: A clinical report. J Prosthet Dent. 2021;doi: 10.1016/j.prosdent.2020.12.045.
6. Aydemir CA, Arısan V. Accuracy of dental implant placement via dynamic navigation or the freehand method: A split-mouth randomized controlled clinical trial. Clin Oral Implants Res. 2020;31(3):255-63.
7. Stefanelli LV, DeGroot BS, Lipton DI, Mandelaris GA. Accuracy of a Dynamic Dental Implant Navigation System in a Private Practice. Int J Oral Maxillofac Implants. 2019;34(1):205–13.
8. Zhen F, Fang W, Jing S, Zuolin W. The use of a piezoelectric ultrasonic osteotome for internal sinus elevation: a retrospective analysis of clinical results. Int J Oral Maxillofac Implants. 2012;27(4):920-6.
9. Sohn DS, Lee JS, An KM, Choi BJ. Piezoelectric internal sinus elevation (PISE) technique: a new method for internal sinus elevation. Implant Dent. 2009;18(6):458-63.

10. Edelmann C, Wetzel M, Knipper A, Luthardt RG, Schnutenhaus S. Accuracy of Computer-Assisted Dynamic Navigation in Implant Placement with a Fully Digital Approach: A Prospective Clinical Trial. J Clin Med. 2021;10(9):1808.
11. Stefanelli LV, Mandelaris GA, DeGroot BS, Gambarini G, De Angelis F, Di Carlo S. Accuracy of a Novel Trace-Registration Method for Dynamic Navigation Surgery. Int J Periodontics Restorative Dent. 2020;40(3):427-35.
12. Gargallo-Albiol J, Barootchi S, Salomó-Coll O, Wang HL. Advantages and disadvantages of implant navigation surgery. A systematic review. Ann Anat. 2019;225:1-10.
13. Chen CK, Yuh DY, Huang RY, Fu E, Tsai CF, Chiang CY. Accuracy of Implant Placement with a Navigation System, a Laboratory Guide, and Freehand Drilling. Int J Oral Maxillofac Implants. 2018;33(6):1213-8.
14. Sun TM, Lee HE, Lan TH. Comparing Accuracy of Implant Installation with a Navigation System (NS), a Laboratory Guide (LG), NS with LG, and Freehand Drilling. Int J Environ Res Public Health. 2020;17(6):2107.
15. Wu D, Zhou L, Yang J, Zhang B, Lin Y, Chen J, Huang W, Chen Y. Accuracy of dynamic navigation compared to static surgical guide for dental implant placement. Int J Implant Dent. 2020;6(1):78.
16. Block MS, Emery RW, Lank K, Ryan J. Implant Placement Accuracy Using Dynamic Navigation. Int J Oral Maxillofac Implants. 2017;32(1):92-9.
17. Pellegrino G, Bellini P, Cavallini PF, Ferri A, Zacchino A, Taraschi V, Marchetti C, Consolo U. Dynamic Navigation in Dental Implantology: The Influence of Surgical Experience on Implant Placement Accuracy and Operating Time. An in Vitro Study. Int J Environ Res Public Health. 2020;17(6):2153.
18. Summers RB. The osteotome technique: Part 3–Less invasive methods of elevating the sinus floor. Compendium. 1994;15:698-708.
19. Kühl S, Kirmeier R, Platzer S, Bianco N, Jakse N, Payer M. Transcrestal maxillary sinus augmentation: Summers' versus a piezoelectric technique–an experimental cadaver study. Clin Oral Implants Res. 2016;27(1):126-9.
20. Lundgren S, Cricchio G, Hallman M, Jungner M, Rasmusson L, Sennerby L. Sinus floor elevation procedures to enable implant placement and integration: techniques, biological aspects and clinical outcomes. Periodontol 2000. 2017;73(1):103-20.
21. Pjetursson BE, Lang NP. Sinus floor elevation utilizing the transalveolar approach. Periodontol 2000. 2014;66(1):59-71.
22. Sohn DS, Ahn MR, Jang BY. Sinus bone graft using piezoelectric surgery. J Korean Acad Oral Maxillofac Implantol. 2003;9:48-55.
23. Block MS, Emery RW, Cullum DR, Sheikh A. Implant Placement Is More Accurate Using Dynamic Navigation. J Oral Maxillofac Surg. 2017;75(7):1377-86.
24. Varga E Jr, Antal M, Major L, Kiscsatári R, Braunitzer G, Piffkó J. Guidance means accuracy: A randomized clinical trial on freehand versus guided dental implantation. Clin Oral Implants Res. 2020;31(5):417-30.

25. Vercruyssen M, Cox C, Coucke W, Naert I, Jacobs R, Quirynen M. A randomized clinical trial comparing guided implant surgery (bone- or mucosa-supported) with mental navigation or the use of a pilot-drill template. J Clin Periodontol. 2014;41(7):717-23.
26. Pozzi A, Moy PK. Minimally invasive transcrestal guided sinus lift (TGSL): a clinical prospective proof-of-concept cohort study up to 52 months. Clin Implant Dent Relat Res. 2014;16(4):582-93.
27. Rammelsberg P, Kilian S, Büsch C, Kappel S. The effect of transcrestal sinus-floor elevation without graft on the long-term prognosis of maxillary implants. J Clin Periodontol. 2020;47(5):640-8.

Figures

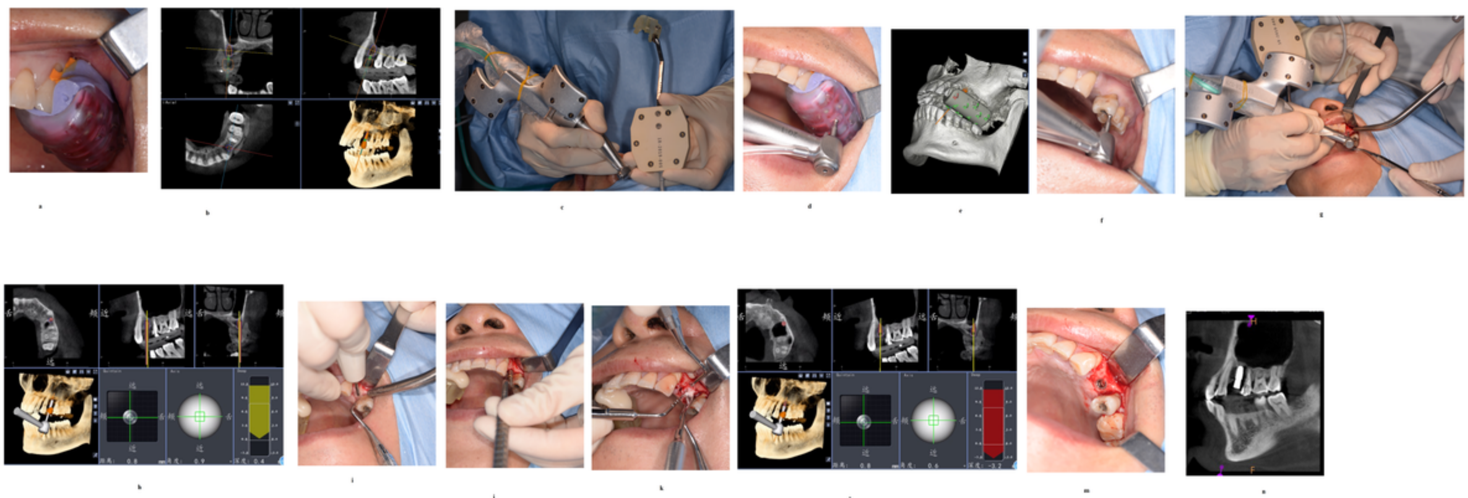


Figure 1

1a All patients should have a registration device fitted in the surgical site using silicone elastomer before undergoing cone-beam computed tomography scanning

1b Suitable three-dimensional virtual position for a left maxillary first premolar implant as planned in the dynamic navigation software

1c During the calibration step, the spherical portion of the drilling needle is close to the hemispherical groove specified on the reference device

1d, e The registration device was placed onto the surgical site, while a reference device with a fixing device was affixed onto the other side of the same jaw, and a short ball drill was installed on the handpiece to collect the specific ball pit information on the registration device

1f The drill was placed on the cusp of the tooth to determine whether the drill position displayed in the dynamic navigation system was accurate

1g Using the handpiece and drills in a left maxillary first premolar implant surgical procedure with dynamic navigation system guidance

1h The navigation screen shows that the drill has reached the designed position at the bottom of the maxillary sinus floor

1i A piezoelectric surgical tip was used to break through the maxillary sinus floor

1j After penetrating the maxillary sinus floor, osteotomes were used to elevate the sinus membrane

1k The graft was compacted into the osteotomy site

1l The implant was inserted into the surgical site under the direct view of the dynamic navigation system

1m An oral image of the left maxillary first premolar implant

1n A postoperative CBCT scan of the left maxillary first premolar implant

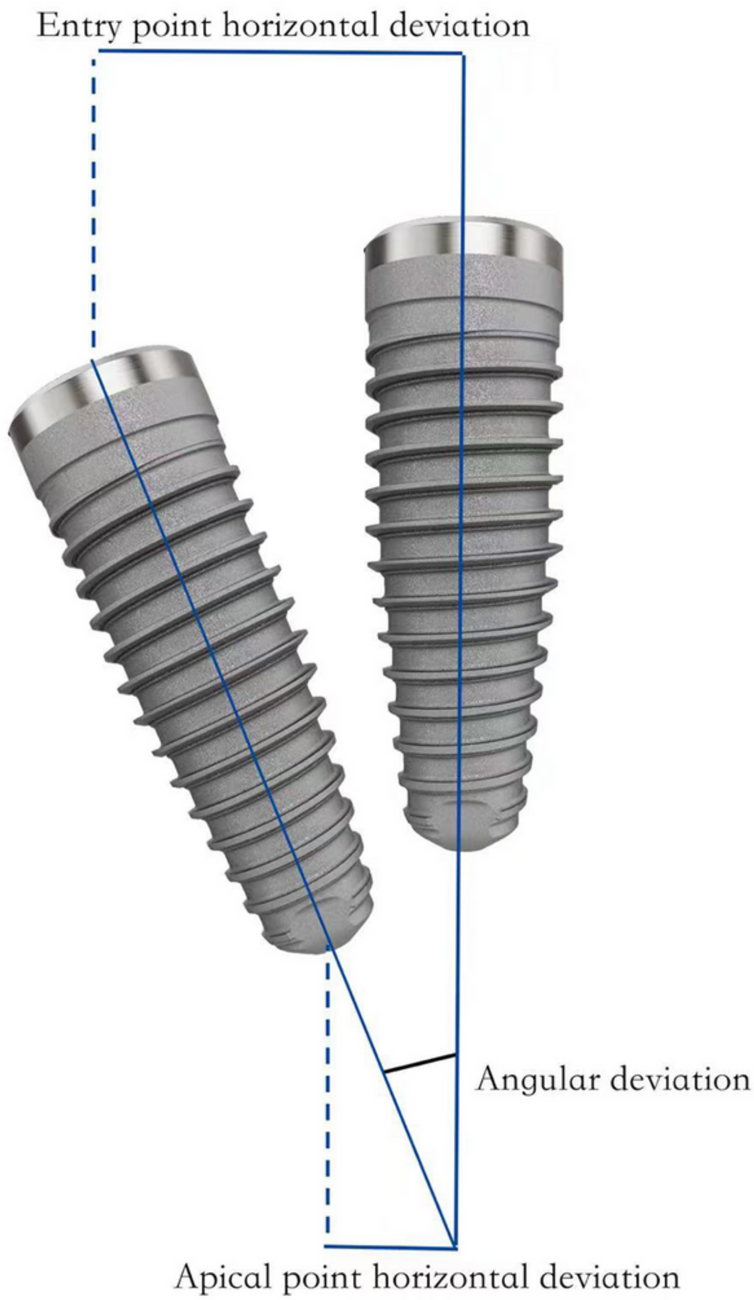
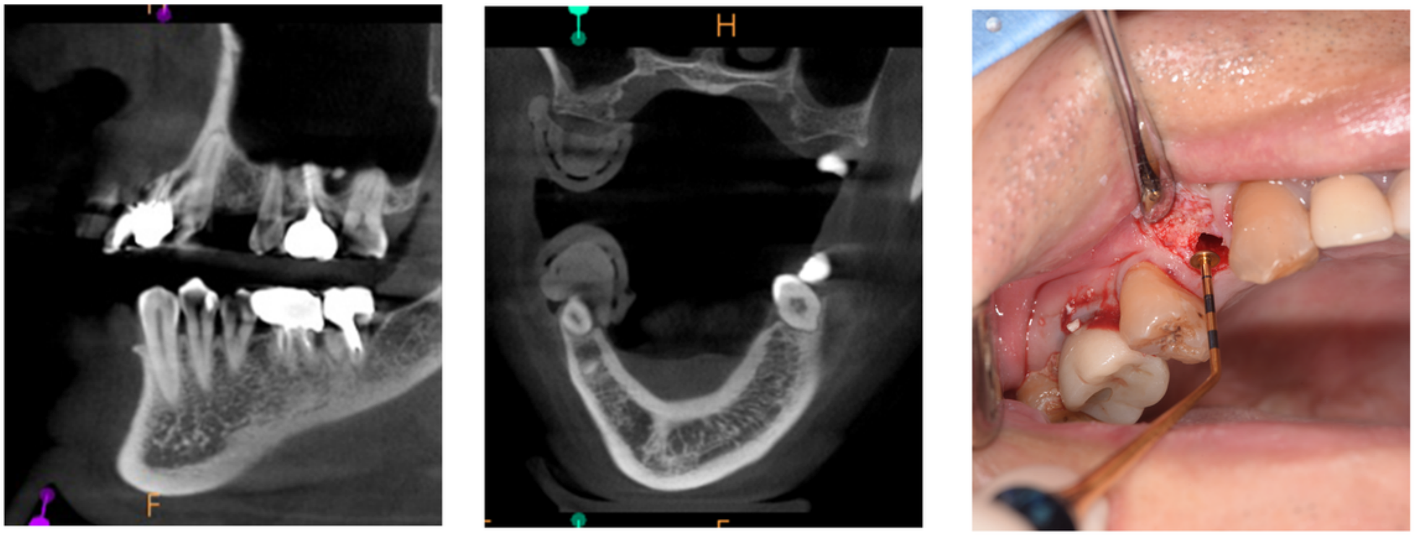

Entry point horizontal deviation
Angular deviation
Apical point horizontal deviation

Figure 2



a b c

Figure 3

a A premolar with a mesiodistal sloping maxillary sinus floor

b A molar with a buccolingual sloping maxillary sinus floor

c A dome-shaped elevator was used