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Accuracy of intentionally tilted implant placement in the maxilla using dynamic navigation: a retrospective clinical analysis

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T. Meng, X. Zhang: Accuracy of intentionally tilted implant placement in the maxilla using dynamic navigation: a retrospective clinical analysis. Int. J. Oral Maxillofac. Surg. 2022; 51: 552–557.

Abstract. The aim of this retrospective study was to investigate the accuracy of dynamic navigation for the placement of intentionally tilted implants in the posterior maxilla. The study included 12 patients with edentulism or continuous multiple tooth loss, who had 48 implants inserted under dynamic navigation guidance in the posterior maxilla. Twenty-four implants near maxillary sinuses were intentionally tilted. The average platform deviation was 1.3 ± 0.4 mm (range 0.8–2.3 mm), apex deviation was 1.1 ± 0.5 mm (range 0.2–2.3 mm), and axis deviation was 3.1 ± 1.0° (range 1.8–6.7°). The other 24 implants were axially positioned. The average platform deviation was 1.5 ± 0.5 mm (range 0.7–3.1 mm), apex deviation was 1.3 ± 0.7 mm (range 0.5–3.1 mm), and axis deviation was 3.2 ± 1.5° (range 1.5–7.7°). There was no significant difference in platform deviation, apex deviation, or axis deviation between the tilted implants and implants in the axial position ($P > 0.05$). This analysis indicates that a dynamic navigation system can be used as a method of guidance to place intentionally tilted implants as accurately as axially positioned implants in the posterior maxilla, thereby preventing damage to the maxillary sinuses and the need to graft bone.

Key words: dental implantation; maxilla; surgical navigation systems; retrospective studies; cone-beam computed tomography.

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Implants need to be placed in optimal positions to ensure favourable long-term treatment outcomes in terms of the state of the prosthesis and the health of the peri-implant tissue. The emphasis during surgery is sufficient height and thickness of the bone wall, prosthetically driven implantation, and low-trauma tissue handling[1,2]. Since the introduction of dynamic navigation technology in dental implantology in the 1990s[3], many benefits have been shown. First, the surgeon can use this technology to plan the positions of implants preoperatively[4]. Second, this technology helps the surgeon insert implants accurately according to the implant plan with real-time images[5]. Finally, this technology can be used for patients with a limited mouth opening and difficult-to-access locations, such as the posterior areas of the jaws[6].

Dynamic navigation is used to track the positions of the patient and the hand piece when holes are drilled and implants are placed using optical technologies. A monitor is used to visually display the positions of the burs and implants in real time. There are both passive and active dynamic navigation systems. In passive systems, tracking arrays reflect light emitted from a light source to stereo cameras. In active systems, tracking arrays directly emit light to stereo cameras[6].

Insufficient vertical bone volume in the posterior region of the maxilla often complicates implant insertion[7]. Although bone grafting techniques successfully overcome the problem of insufficient vertical bone volume[8], there are limitations of bone grafting techniques, including a long healing time and biological complications[9,10]. To overcome the limitations of bone grafting techniques, implantologists have proposed the use of distal intentionally tilted implants in the posterior maxilla[11]. The clinical performance of intentionally tilted implants is equivalent to that of implants in an axial position[12,13]. The use of distal intentionally tilted implants can maximize the utilization of available bone volume in the posterior maxilla, decrease the need for bone augmentation, enhance implant primary stability when long implants are used, and shorten the cantilever[11,13,14].

Based on the advantages mentioned above, dynamic navigation is considered a promising technology for placing intentionally tilted implants. However, few studies on the accuracy of dynamic navigation for intentionally tilted implants have been published.

The aim of this retrospective clinical study was to investigate the accuracy of dynamic navigation for the placement of intentionally tilted implants in the posterior maxilla.

Materials and methods

This study was approved by the Human Research Ethics Committee of Peking University School and Hospital of Stomatology.

Patient selection

Patients who underwent implant therapy between September 2019 and January 2021 at the First Clinical Division, Peking University School and Hospital of Stomatology were selected and analysed retrospectively. Available patients were selected consecutively if they met the inclusion criteria.

The inclusion criteria were as follows: (1) edentulism or continuous multiple tooth loss in the maxilla; (2) Cawood and Howell class III maxillary atrophy; (3) vertical bone height in the posterior maxillary region, referring to the maxillary region from premolars to molars, less than 6 mm; and (4) intentionally tilted implants to be placed in the maxilla under dynamic navigation.

The following exclusion criteria were applied: (1) cases without intentionally tilted implants; (2) cases without postoperative cone beam computed tomography (CBCT) scans; and (3) cases with horizontal ridge augmentation.

Treatment procedure

The patients underwent routine clinical examinations. They were informed about the dynamic navigation technology and the treatment procedure. All patients signed informed consent forms.

On the day of the operation, six titanium microscrews were inserted into the maxillary bone transmucosally under infiltration anaesthesia. The patient underwent a preoperative CBCT scan with the intraoral microscrews in place. The DICOM dataset was inputted into the active dynamic navigation system (DHC-DI2; Digital-health Care Co. Ltd., Suzhou, China). The positions of the virtual implants were adjusted in three-dimensional views selected arbitrarily by the design software (Dental Implant Navigation System; Digital-health Care Co. Ltd.) (Fig. 1). To avoid damage to the maxillary sinus and the grafting of bone, virtual implants near the maxillary sinuses were tilted intentionally (Fig. 2). Other implants in the posterior region of the maxilla were positioned axially. The final digital implant treatment plans were performed.

Under routine local anaesthesia and following flap reflection, a Straumann implant (Straumann Group, Basel, Switzerland) was inserted in a freehand manner in the anterior region of the maxilla to fix the reference frame. A registration procedure was then performed. Microscrews acted as fiducial markers to align the digital plan with the anatomy of the patient. After registration, the positions of the burs and CBCT images containing the outlines of the virtual implants were displayed simultaneously on the monitor. Digital representations of the burs were shown on the monitor in real time during drilling (Fig. 3). Straumann BLT implants (Straumann Group, Basel, Switzerland) 3.3–4.1 mm in diameter and 10 mm in length were placed under dynamic navigation guidance. At least 25 Ncm of insertion torque was achieved for all implants. After the implants had been inserted, healing screws were placed and the wound was sutured. The operation time from local anaesthesia to wound closure was recorded. After the implant surgery, the patient underwent another CBCT scan (Fig. 4).

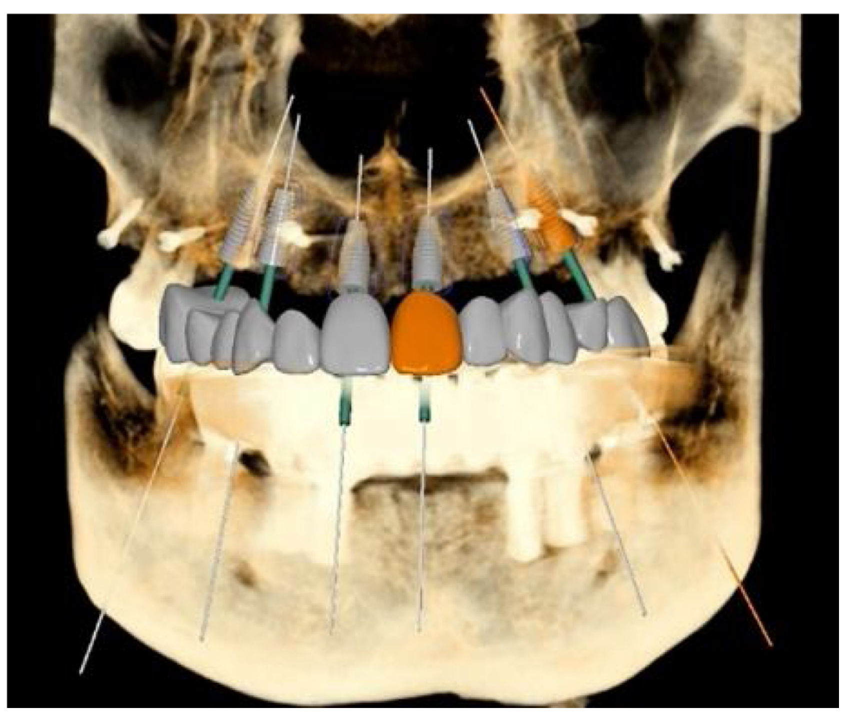

Fig. 1. The positions of virtual restorations and the positions of implants were planned.

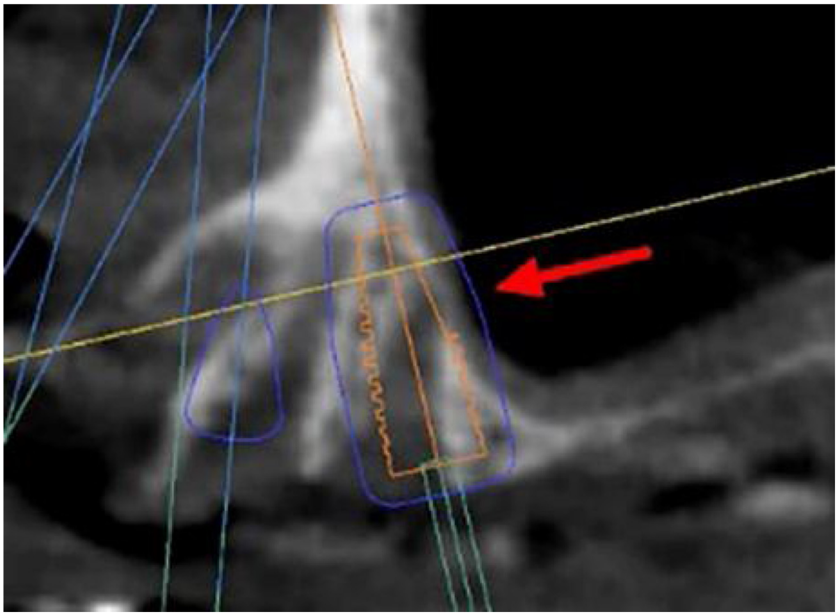

Fig. 2. Tilted implant position planning. The implant adjacent to the maxillary sinus was intentionally tilted, as indicated by the arrow.

No patient received a provisional fixed prosthesis immediately after implant placement. After at least 3 months, all patients received zirconia–ceramic implant-supported multiple-unit fixed dental prostheses.

Measurements

The implant treatment plan and postoperative CBCT scan were aligned using an algorithm in the implant accuracy analysis system (ImplantPrecisionSys; Digital-health Care Co. Ltd.). This software superimposed the implant treatment plan and postoperative CBCT scan using several markers, such as the mental foramen and the nasal spine. The software automatically calculated whether the two images were precisely aligned. Once the alignment was finished, the software automatically fit the virtual implants to their appearance in the postoperative CBCT image and automatically computed the deviation between the actual and virtual implant positions (Fig. 5). Three types of deviation were assessed: (1) platform deviation: the linear deviation in millimetres between the actual and virtual implants at the centre of the platform; (2) apex deviation: the linear deviation in millimetres between the actual and virtual implants at the centre of the apex; and (3) axis deviation: the deviation in degrees between the actual and virtual implants at the centre axis line.

Statistical analysis

The data are shown as the mean ± standard deviation (minimum–maximum). The deviation data were not normally distributed, so the non-parametric Mann–Whitney *U*-test was applied to assess the difference between distal intentionally tilted implants and axially positioned

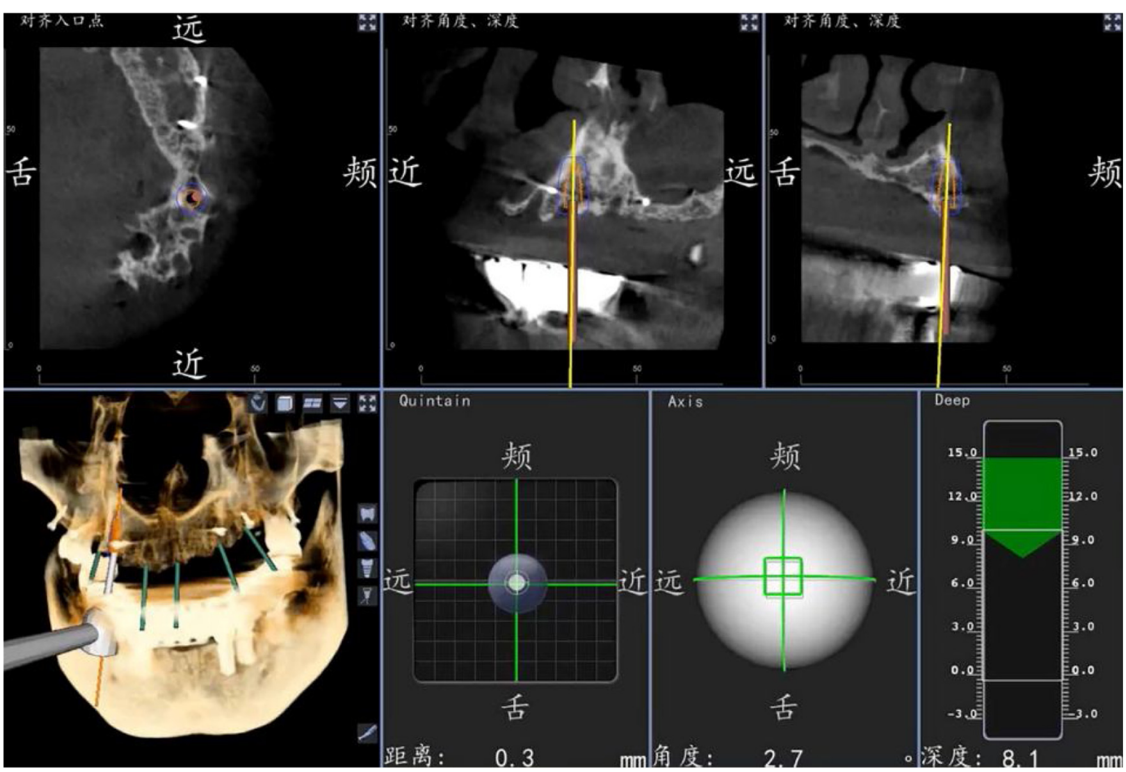

Fig. 3. Digital representations of the burs shown on a monitor in real time.

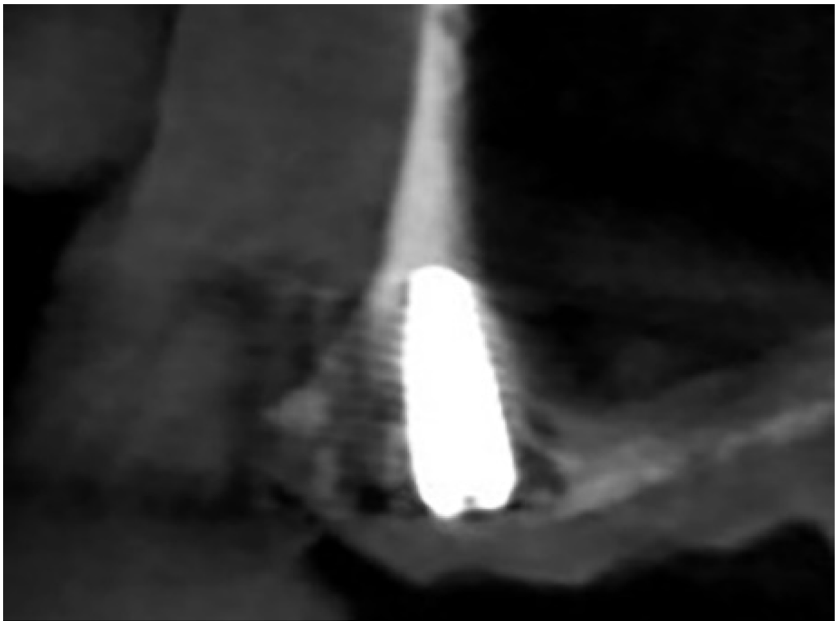

Fig. 4. Postoperative CBCT of the tilted implant.

implants. $P < 0.05$ was considered statistically significant. The data were entered into IBM SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA) for analysis.

Results

Twelve patients, seven female and five male, between the ages of 56 and 73 years, received 48 implants in the posterior maxilla. Of these 48 implants, 24 were distally intentionally tilted, while the other 24 were inserted axially under guidance with the dynamic navigation system. The average operation time for maxillary implant insertion was 81.9 ± 7.9 minutes (70.0–95.0 minutes).

The average displacement errors of the implant platform, apex, and axis for the 24 tilted implants and 24 implants in the axial position are reported in Table 1.

There was no significant difference in platform deviation, apex deviation, or axis deviation between the tilted implants and the implants in the axial position, with $P > 0.05$ (Table 1).

Discussion

A dynamic navigation system was used as a method of guidance to accurately place intentionally tilted implants in the optimal positions. Using dynamic navigation, the surgeons made preoperative plans for the optimal positions of the implants according to the available bone volume and prosthodontics, avoiding damage to the critical structures and guaranteeing that the inclination of the distal implants was within a reasonable range[15,16].

Studies in the literature have reported improved accuracy with dynamic navigation. In vitro studies have reported a mean linear error of less than 2 mm and mean angular error of less than 5°[17–19], and dynamic navigation has been shown to lead to smaller angular and axial errors than the freehand method[20]. In vivo, dynamic navigation has also been shown to accurately guide implant placement. For patients requiring at least one implant, the navigation system has been shown to decrease the mean linear discrepancy for both the platform and apex to less than 1.6 mm and to decrease angle errors to approximately 4° when compared to the freehand method[16,21–23]. A meta-analysis by Jorba-García et al. recently demonstrated that the mean angular deviation of dynamic navigation systems was less than 4° and that the mean entry deviation and mean apex deviation were 1.03 mm and 1.34 mm, respectively, resulting in greater implant placement accuracy than freehand implant placement and slightly less angular deviation than implant placement using static computer-assisted implantation systems[24].

The dynamic navigation system used in the present study was a new brand, but its accuracy is comparable to that of other dynamic navigation systems and static surgical templates. Wu et al. showed that the platform deviation, apical deviation, and angular deviation in the dynamic navigation group were 1.36 ± 0.65 mm, 1.48 ± 0.65 mm, and 3.71 ± 1.32°, respectively, while in the static surgical template group they were 1.22 ± 0.70 mm, 1.33 ± 0.73 mm, and 4.34 ± 2.22°, respectively[25]. Sun et al. demonstrated that the angular error of dynamic navigation was 3.24 ± 0.36°[26], while the mean angular deviation was 4.1° for a static guide in another study[27]. A systematic review and meta-analysis of clinical studies showed

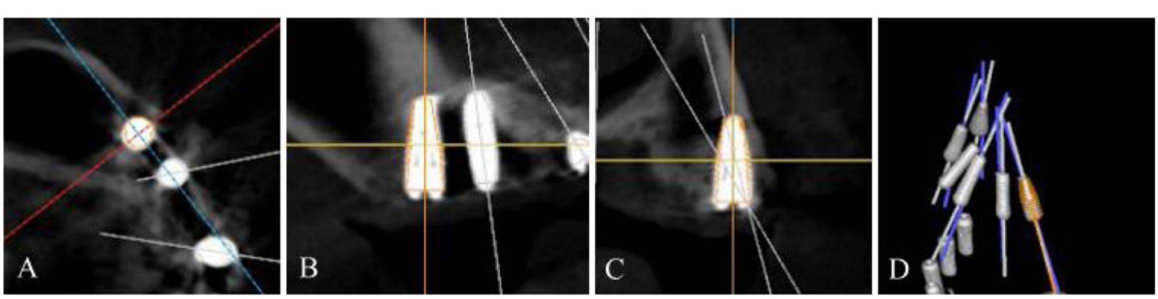

Fig. 5. Visual presentation of the deviations calculated by the implant accuracy analysis system: (A) coronal plane; (B) axial plane; (C) sagittal plane; (D) three-dimensional representation.

Table 1. Deviations between actual implants and virtual implants.

	Intentionally tilted implants			Axially positioned implants			Z	P-value
	Mean ± SD	Max	Min	Mean ± SD	Max	Min		
Platform (mm)	1.3 ± 0.4	2.3	0.8	1.5 ± 0.5	3.1	0.7	−1.204	0.228
Apex (mm)	1.1 ± 0.5	2.3	0.2	1.3 ± 0.7	3.1	0.5	−0.538	0.591
Axis (°)	3.1 ± 1.0	6.7	1.8	3.2 ± 1.5	7.7	1.5	−0.289	0.772

Max, maximum; Min, minimum; SD, standard deviation.

that the global coronal deviation was 1.00 mm, the global apex deviation was 1.33 mm, and the angular deviation was 4.1° for dynamic navigation[28]. Meanwhile, another meta-analysis of the accuracy revealed a total mean error of 1.2 mm (1.04–1.44 mm) at the entry point and 1.4 mm (1.28–1.58 mm) at the apical point, and a deviation of 3.5° (3.0–3.96°) for static computer-assisted implantation systems[29]. The accuracy of intentionally tilted implants and axially positioned implants inserted under dynamic navigation guidance in the present study is similar to that reported in previous studies.

Nevertheless, previous studies have focused on the accuracy of axially positioned implants, and few studies have demonstrated the accuracy of intentionally tilted implants under the guidance of dynamic navigation. This study showed that there was no significant difference in deviation between the 24 tilted implants and 24 implants in the axial position, and that the accuracy of the tilted implants was similar to that reported in the previous literature for axial implants with dynamic navigation, which indicates that intentionally tilted implants were as accurate as axially positioned implants under the guidance of a dynamic navigation system.

However, the maximum axis deviations were relatively large in this study. The maximum deviation of the axis reached 6.7° for tilted implants. There are three possible reasons for the deviations. First, shifts in preoperative CBCT data, which resulted from head motion of the patient during the CBCT scan, decreased the accuracy of the digital models calculated from CBCT data for implant planning and navigation. Second, the manual matching procedure after the operation possibly resulted in errors because of the patients shifting in the postoperative CBCT scans and system errors in the software. Third, a lack of surgeon experience with operating the navigation system may have led to errors. Research on learning curves has indicated that at least five training courses for navigation systems and strict compliance at each step are necessary for dentists to ensure patient safety and reliability in implant procedures[30]. Another study showed that the difference in accuracy between surgeons with previous experience with dynamic navigation and surgeons without experience with dynamic navigation can reach a minimum after 20 cases[22].

Static surgical templates or implant guides do not allow surgeons to observe or adjust the positions of burs during surgery. In contrast, dynamic navigation provides real-time images for surgeons to observe and adjust the positions of burs. Furthermore, dynamic navigation was found to facilitate the placement of intentionally tilted implants in the posterior region of the maxilla without templates in the patient's mouth, which improved patient comfort. A considerable disadvantage of dynamic navigation is the long time required for registration. The registration time was approximately 10–15 minutes in the patients included in this study. The development of optimized systems and greater experience with the system may reduce the registration time.

This retrospective study was preliminary and included few cases. Prospective research including more cases is required in the future. Immediate loading with dynamic navigation in edentulous patients as well as the cost-effectiveness of the system should be analysed in the future.

This retrospective clinical analysis indicated that in cases without sufficient vertical bone in the posterior maxilla, a dynamic navigation system can be used as a method of guidance to place intentionally tilted implants as accurately as axially positioned implants, thereby preventing damage to the maxillary sinuses and the need to graft bone.

Funding

There were no sources of funding for this research.

Competing interests

There are no conflicts of interest to declare.

Ethical approval

This study was approved by the Human Research Ethics Committee of Peking University School and Hospital of Stomatology (study code: PKUSSIRB-202057108).

Patient consent

This study did not require clinical photographs. The Biomedical Ethics Committee of the Peking University Hospital of Stomatology approved the application for freedom from the requirement for written informed patient consent.

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