Original Article

Comparative evaluation of accuracy between dynamic navigation and freehand method during orthodontic implant placement: a split-mouth study

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ABSTRACT

Objectives: To assess and compare the accuracy of infrazygomatic crest screws (IZC) placed with and without a dynamic navigation system.

Materials and Methods: Preoperative cone-beam computed tomography (CBCT) and intraoral scan of the maxillary arch were obtained for 12 patients requiring therapeutic first premolar extraction after leveling and alignment. Virtual planning of the final IZC screw position on both sides was done using Evalunav software. Maxillary left and right arches for each patient were randomized into experimental and control sides. A 12 $\times$ 2 mm dimension IZC screw was positioned with and without use of a dynamic navigation system randomly on either side. A postoperative CBCT was taken immediately to assess the final screw position. Preoperative and postoperative CBCTs were compared for deviation in the entry point, apical point, and angular point for experimental and control sides. Mean value deviations obtained were subjected to statistical analysis using SPSS 20.0 to describe the data.

Results: Paired *t*-tests were used to analyze the comparisons. Dynamic navigation showed a statistically significant difference in entry point and angular point compared to the freehand approach during implant placement.

Conclusions: IZC screws implanted with the dynamic navigation system offered better control with less deviation and greater accuracy in all three planes of space. However, further studies are necessary to determine the stability and anchor value of implants placed with a dynamic navigation system. (*Angle Orthod*. 2025;00:000–000.)

KEY WORDS: Dynamic navigation; Infrazygomatic crest; Temporary anchorage devices; Virtual planning; Computer-assisted surgery; Guided surgery

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INTRODUCTION

Patients often seek orthodontic treatment to correct inclination of the maxillary incisors, which is primarily done by extraction of the maxillary first premolars, requiring critical anchorage.[1] This can be achieved by using temporary anchorage devices (TADs), which are effective for arch retraction and intrusion with minimal patient compliance.[2] Generally, TADs can be placed as either intraradicular or extraradicular to facilitate various tooth movements. Intraradicular implants are more popular because of their small size and simple operative procedure but they involve the risk of root damage and loosen occasionally, failing to provide firm anchorage.[3] Therefore, these intraradicular screws are gradually being replaced with more robust extraradicular screws such as infrazygomatic crest screws and buccal shelf screws.

In the maxillary arch, ideally, these extra radicular screws are positioned in the infrazygomatic crest (IZC) region. It is the bony, palpable ridge with varied thickness of 4.5 mm to 9 mm between the alveolar ridge and the zygomatic process of the maxilla. The position of the IZC varies with age. In younger individuals, it is more mesial and may be between the maxillary second premolar and first molar. In adults, it is slightly distal and buccal to the maxillary first molar, providing bicortical anchorage.[4]

IZC screws are typically 10 to 14 mm long with a minimum width of 2 mm, which is much larger than conventional miniscrews that are 6 to 11 mm long and 1.3–2 mm in diameter. IZC screws are placed 11 to 17 mm above the occlusal plane at an angle of 55°– 70° to avoid damage to the maxillary sinus or the nasal floor, which are the closest anatomical structures in the infrazygomatic crest area.[5] Any deviation from this ideal position may lead to maxillary sinus perforation or persistent chronic sinus inflammation. Therefore, detailed planning and exact execution of the plan is essential to accomplish accurate insertion and patient-specific results, with less post-operative pain and swelling in the surgical area.

Conventional methods, such as the freehand placement technique or the use of a surgical guide, did not give a reliable reproduction of the ideal planned position of the implant in the surgical site. Computer-aided implant surgeries (CAIS) were later introduced to increase the precision of implant placement and eliminate any hypothetical complications.[6] They would broadly fall under the categories of static-guided implantation and dynamically navigated implant systems. CAIS has drastically improved implant placement by providing the surgeon with a real-time navigation tool by tracking the implants and drills through an optimal marker and relating information to the three-dimensional preoperative virtual plan drawn up with CBCT and surface scans.[7]

Dynamic navigation is more popular in the field of prosthodontics for guided implant placement. Registration, calibration, and tracking are the three fundamental steps that enable correlation of the planned CBCT image volume to real-time mapping of the drill tip.[8] Registration relates the patient tracking array to the fiducials and the planned implants. Calibration determines the relationship between the geometry of the handpiece tracking array and the axis of the drill.[9] Tracking utilizes a micron tracker camera and relates the position of the patient's jaw to the implant drill tip, which is displayed instantly on the monitor in real time, allowing for continuous, immediate feedback on the mesiodistal, buccolingual, and apicocoronal positions with improved accuracy ranging to sub millimeter levels.[10] CBCT data are used to merge the digitized prosthetic planning with the actual anatomical position of the implant. Advantages include minimizing damage to important structures, mobilizing less flap, and achieving minimally invasive surgery to place implants accurately at proper angulations in exact locations characterized by difficult access with high esthetic needs.[11]

Therefore, the aim of this study was to evaluate and compare the placement accuracy of infrazygomatic crest screws with and without dynamic navigation.

MATERIALS AND METHODS

Trial Design and Commencement

This clinical experiment was designed as a single-center, split-mouth, randomized controlled study. It was double-blind and used a 1:1 allocation scheme in which the right side of each patient was randomly assigned as the experimental or control side, while the contralateral side received the opposite treatment, concurrently. The Consolidated Standards of Reporting Trials (CONSORT) statement and guidelines were followed during this randomized clinical trial. No alterations were made to the methodology after trial commencement.

Trial Registration

The IECVDC/2022/PG0I/ODFO/IVV/37 study protocol was approved by the Research Ethics Committee and the Institutional Review Board, Vishnu Dental College. This randomized clinical trial was registered at Clinicaltrials.gov under the number CTRI/2022/07/044244. Patients who visited the orthodontic department of Visnu Dental College between June 2022 and August 2023 were assessed for bimaxillary protrusion, and those who needed skeletal anchorage were included in the study. A written, informed consent prior to research participation was obtained from the patient. Neither the subject nor the secondary investigator was aware of the side of the arch for which the experimental procedure was carried out.

Eligibility Criteria

Inclusion criteria

1. Patients who required bilateral therapeutic premolar extraction with maximum or absolute anchorage
2. Patients who required distalization of maxillary dentition
3. Permanent dentition with age ranging from 18–25 years
4. Patients without pneumatization of the maxillary sinus cavity
5. Patients who had sufficient buccal alveolar bone thickness in the molar region

Exclusion criteria

1. Patients having any bone diseases
2. Patients with cleft lip and palate
3. Patients with any previous history of allergies to local anesthetics or antibiotics

Figure 1. 2 × 12 mm infrazygomatic crest screw.

4. Patients with any missing permanent teeth or unerupted teeth (molars)
5. Patients with skeletal Class III malocclusion

Sample Recruitment

All patients recruited for the study were initially assessed for maxillary sinus height on pretreatment panoramic radiographs. Sinus height was measured from the infraorbital marginal rim to the maxillary sinus border lining. Those with increased height (maxillary sinus pneumatization) were excluded from the study. Fixed appliances (0.022-inch MBT metal prescription brackets) were bonded. Maxillary first premolars were extracted bilaterally before the start of fixed orthodontic treatment. Leveling and alignment were done using a standard approach with a preset sequence of 0.014-inch, 0.016-inch nickel-titanium (NiTi) for 8 weeks, 0.018-inch, 17 × 25-inch NiTi for 8 weeks, and 19 × 25-inch NiTi and 19 × 25-inch ss for 8 weeks. The leveling and alignment phase lasted for 20–24 weeks.

Radiographic Evaluation

After leveling and alignment in the maxillary arch, cone beam computed tomography (CBCT, Cranex 3D Soredex device) was used to determine the buccal alveolar bone thickness at the infrazygomatic crest area. It was measured by drawing a line from the middle of the root apex to the most prominent point on the buccal cortical plate at 14–16 mm above the maxillary occlusal plane. The image was aligned in the coronal view, then on the sagittal axis to ensure symmetrical bone architecture so that a 0° line passed through the alveolar crest at

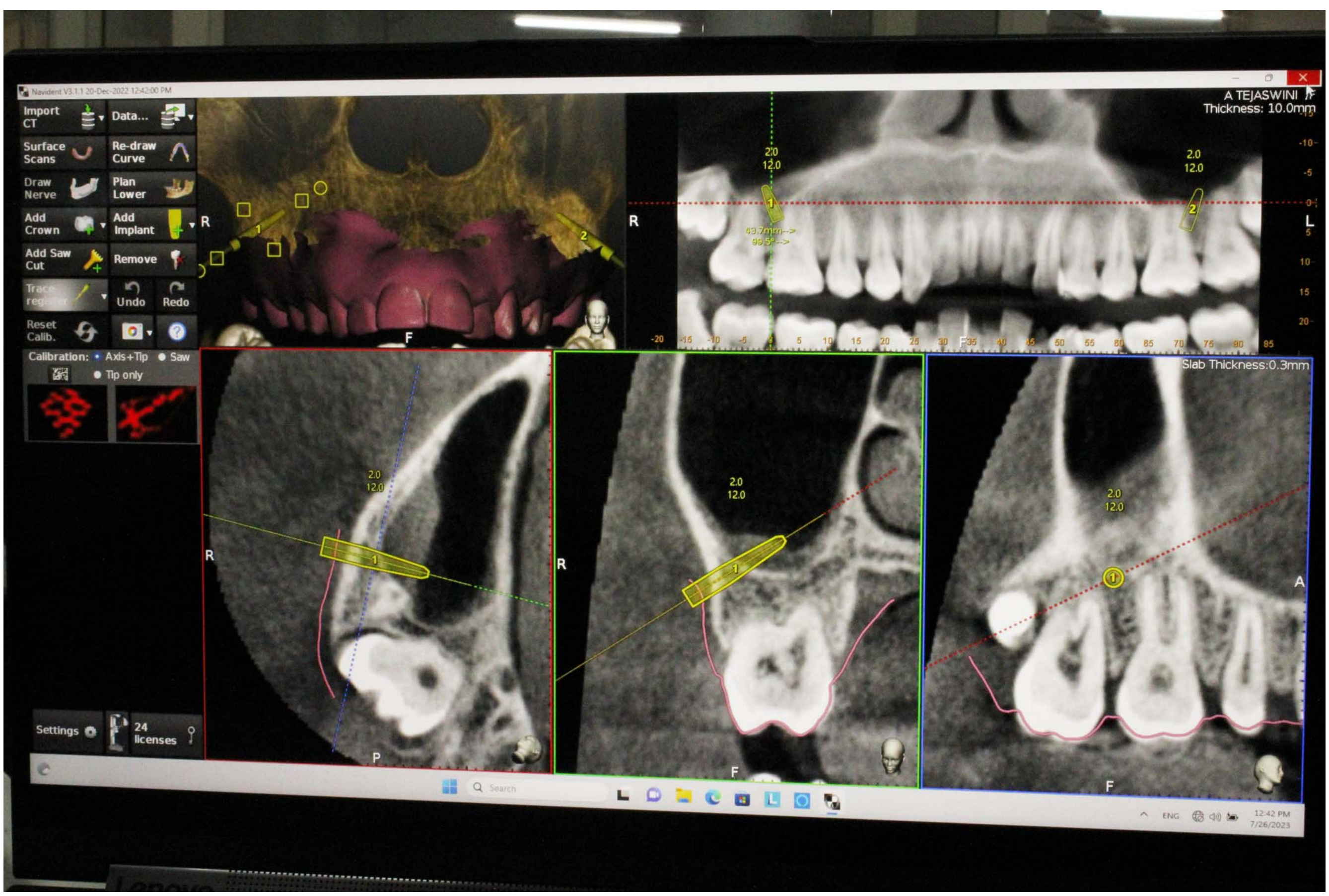

Figure 2. Virtual planning of position of the IZC screw. IZC indicates infrazygomatic crest.

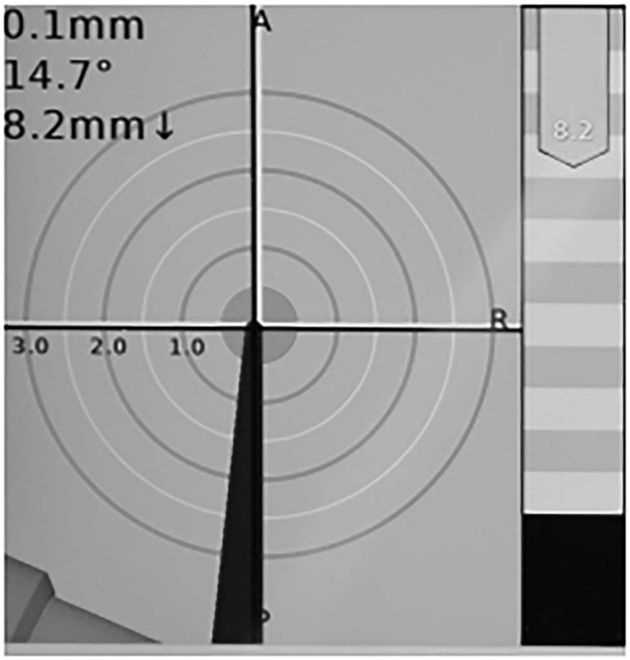

Figure 3. Bullseye representing the actual deviation of IZC screw from the planned position.

the same level on both sides by bringing the axial plane parallel to the palatal plane. After CBCT evaluation, only patients with good alveolar bone thickness were further recruited into the study. Three of the 15 patients had inadequate buccal cortical bone thickness and maxillary sinus pneumatization. Therefore, they were excluded from the study, and only 12 patients were included in the study.

Virtual Planning of Implant Position

Prior to virtual planning, an intraoral scan was obtained for all patients. The intraoral scan and the CBCT were superimposed in the dynamic navigation system software. Key landmarks and three hard tissue points were identified to mimic the soft tissue. Then, a virtual IZC screw with dimensions of 2 × 12 mm (diameter: 2 mm, length: 12 mm, SK surgical, Figure 1) was selected, and the final virtual position was planned as suggested by Liou et al.[12] This position was validated by a secondary investigator.

Patient Preparation

Patients were instructed to rinse their mouth for 30 seconds with chlorhexidine mouthwash. Local anesthesia was administered with epinephrine at a 1:2,00,000 ratio (4% articaine chloride). The dynamic navigation system head and jaw tracker components were fixed onto the patient's head. Then, the fiducial tag with the white and black markings was attached and the surgical handpiece was calibrated. The implant drill-to-maxillary

Table 1. Comparison of Descriptive Statistics Like Mean and Standard Deviation for Experimental and Control Sides

Parameter	Sides	Mean	SD
Entry deviation (mm)	S1	1.24	0.61
	S2	3.17	1.40
Apical deviation (mm)	S1	1.65	0.80
	S2	3.04	2.13
Angular deviation (°)	S1	3.7	1.98
	S2	11.3	6.93

relationship was shown instantly when Navident virtual planning (Figure 2) was projected onto a screen, providing continuous and instant feedback regarding the position of the implant drill.

On the experimental side (S1), an IZC screw was inserted by the primary investigator with the virtual planned position as a reference guide. Insertion torque was set at 35N cm at a speed of 1000 rpm. The accuracy of the IZC screw was determined by the screen bullseye or crosshair indication (Figure 3). Once the implant reached its final depth, it emitted a beeping sound, indicating complete insertion of the implant. A similar approach was followed to place the IZC screw using a surgical handpiece, but without the dynamic navigation system, on the S2 side.

A posttreatment CBCT was taken and the deviations in implant placement were determined in Evalunav software. In patients showing larger deviations between planned and finally positioned implants, those screws were removed and placed close to ideal positions. All the patients were recalled postoperatively after 1 week and checked for implant stability using a Williams probe.

Measuring Outcomes

The primary goal was to evaluate variations in point of entry, apex, and total angular deviation of IZC screws placed with dynamic navigation compared to the freehand method. The secondary goal was to measure stability of the implants.

Sample Size Calculation

The sample size was calculated based on a study by Kniha et al., which used G-Power software. A sample size of 12 patients was obtained with 80% power to detect changes, resulting in an effect size of 0.91 at $\alpha = 0.05$ level.

Randomization

Patients who met the eligibility criteria were assigned to one of two placement techniques: right or left. A computerized random number generator was utilized to allocate each patient to the right side of the letter A/B, which corresponded to the experimental application. The

Table 2. TWO- WAY ANOVA to evaluate the impact of Laterality on Insertion of IZC between two Techniques

	DNS		Free Hand		*P* Value		
Variable	Right	Left	Right	Left	Insertion Technique (IT)	Laterality (L)	IT * L
Entry deviation	1.03 ± 0.63	1.46 ± 0.56	2.98 ± 1.56	3.37 ± 1.34	.001*	.375	.962
Apical deviation	1.45 ± 0.66	1.87 ± 0.95	3.34 ± 2.11	2.75 ± 2.32	.053	.901	.467
Angular deviation	3.95 ± 2.49	3.45 ± 1.52	13.38 ± 7.54	9.34 ± 6.24	.003*	.289	.406

$P < .05$ – Statistically Significant.

alternate letter was used on the control side. Randomization ensured a 1:1 allocation ratio.

Blinding

Blinding of the operator was not possible. The examiner measuring the deviations was blinded to the treatment allocation as they were not involved in any clinical procedures and could not identify the type of intervention done to the patient.

RESULTS

Statistical Analysis

All data were analyzed statistically using IBM SPSS version 20 software (IBM SPSS, IBM Corp., Armonk, NY, USA).

Descriptive statistics of mean and standard deviation were calculated for every patient and paired *t*-tests were done to analyze intragroup comparisons. When the *P* value was less than .05, the statistical test was regarded as significant (Table 1).

Two-way analysis of variance (Insertion Technique × Side) was used to determine whether laterality affected the location of the infrazygomatic screw. However, no significant interaction impact ($P > .05$) was observed, confirming consistency during insertion ($P > .05$, Table 2).

Independent *t*-test revealed no statistically significant difference between the patient preparation times for both procedures. However, insertion time varied significantly, as the dynamic navigation approach required more time for insertion (Figure 4).

The results showed that there was a statistically significant difference in mean value deviation between dynamic navigation and the freehand technique. At the entry point, the mean value deviation with dynamic navigation was 1.93 mm less than the freehand technique ($P < .001$, Table 3). At the apex, the mean value was 1.39 mm less with dynamic navigation than the freehand technique ($P < .053$, Table 4), which was marginally significant. Overall, total angular deviation showed 7.65° lesser deviation with dynamic navigation ($P < .003$, Table 5), which is statistically significant.

However, within each group, comparison of entry, apical, and angular deviations showed that they were significantly different ($P < .001$, Table 6). None of the patients showed implant loosening after IZC placement.

Secondarily, the distance between the IZC mini-implants and the nearest root surface on the mesial and distal aspects was measured using postoperative CBCT images. Dynamic navigation resulted in a significantly increased mean distance from the root compared to freehand placement ($P < .05$), reducing the risk of root contact. (Figure 5). Also, 100% bicortical engagement

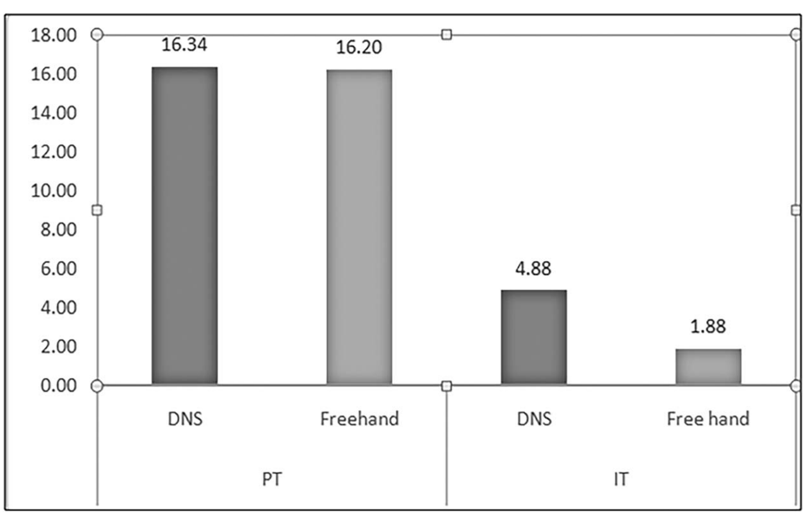

Figure 4. Patient preparation time and insertion time comparison (independent *t*-test).

Table 3. Comparison of Mean Value Entry Deviation Between Experimental and Control Sides

Parameter	Sides	Mean	SD	*P* Value
Entry deviation (mm)	S1	1.24	0.61	.001***
	S2	3.17	1.40	

*** $P = .001$.

of the IZC mini-implants was found on postoperative CBCT for implants placed with both techniques.

DISCUSSION

Anchorage control is crucial when performing orthodontic treatment. The concept of absolute anchorage has led to resurgence in the use of micro-implants and extraradicular bone screws.[1] However, the most common problem reported while placing the screw is pain, which might be due to accidental root contact of the adjacent teeth, minimizing patient cooperation. Thus, there is a need for exploring the methods to position the implant accurately to reduce implant loosening and sinus invasion to facilitate proper force vectors during loading.[3]

This study assessed the positional accuracy of IZC screws rather than mini-implants because they are preferable during leveling and alignment procedures. Gracco et al.[1] reported that any small perforation of 0.2 mm can heal and had no detrimental side effects but a perforation of 1.5 mm depth into the sinus may cause loosening of the miniscrew. There has been debate about the correct anatomical location of IZC screws. Lin et al.[2] placed bone screws in the first and second molar regions, whereas Liou et al.[7] placed them closer to the first molar mesiobuccal root. Therefore, in this study, all the IZC implants were planned virtually to be placed according to the study by Lin et al, which was 14–16 mm apical from the alveolar crest along the mesial root of the maxillary second molar at an angle of 55°–70° to the maxillary occlusal plane to avoid root contact.

The current study focused on comparing the accuracy of orthodontic implant placement using dynamic navigation (DN) vs the freehand method using a split-mouth design. Results confirmed that the dynamic navigation system generally showed superior accuracy in entry and angular deviations compared to the freehand method, in agreement with findings from studies on prosthetic implants.

However, the apical deviation between the two methods in this study was only marginally significant,

Table 4. Comparison of Mean Value Apical Deviation Between Experimental and Control Sides

Parameter	Sides	Mean	SD	*P* Value
Apical deviation (mm)	S1	1.65	0.80	.053 (NS)
	S2	3.04	2.13	

[a] NS indicates nonsignificant.

Table 5. Comparison of Mean Value Angular Deviation Between Experimental and Control Sides

Parameter	Sides	Mean	SD	*P* Value
Angular deviation (°)	S1	3.7	1.98	.003*
	S2	11.3	6.93	

*** $P = .001$.

suggesting that while DN provides better accuracy overall, specific factors such as implant size and location (eg, infrazygomatic crest screws) could influence these outcomes.

The slightly better performance of dynamic navigation in terms of entry deviation (improving accuracy by 20%) may stem from its real-time monitoring capabilities, which allowed for midprocedure adjustments. In contrast, the freehand technique lacked this dynamic feedback, which could explain the observed discrepancies.

Entry Deviation

This study showed a mean entry deviation of 1.65 mm with the dynamic navigation system, significantly lower than the 3.04 mm recorded for the freehand method. The observed reduction in deviation at the entry point, by 1.93 mm ($P < .001$) with Dynamic navigation, was consistent with previous research emphasizing the precision of navigational systems. Vercruyssen et al.[4] highlighted that guided implant surgery, including dynamic navigation, significantly reduced entry point deviations compared to freehand techniques, contributing to more predictable clinical outcomes. Additionally, Jung et al.[8] found that implant placement with navigation systems provided a marked improvement in entry point precision, enhancing the ability to avoid anatomical structures and optimize implant positioning. Brief et al.[10] reinforced these findings by demonstrating similar reductions in entry point deviations, attributing the improvements in accuracy to the continuous intraoperative feedback provided by dynamic navigation systems.

Apical Deviation

In the present study, dynamic navigation resulted in a lesser deviation at the apex by 1.39 mm, with marginal

Table 6. Comparison of Mean Value Deviation at Entry, Apical, and Angular Deviations Within Control and Experimental Sides

Technique	Deviation	Mean	SD	*P* Value
Dynamic navigation	Entry	1.24	0.61	.002**
	Apical	1.65	0.80	
	Angular	3.7	1.98	
Free hand	Entry	3.17	1.40	.001***
	Apical	3.04	2.13	
	Angular	11.3	6.93	

** & *** *P* value statistically significant ($P \leq .05$)

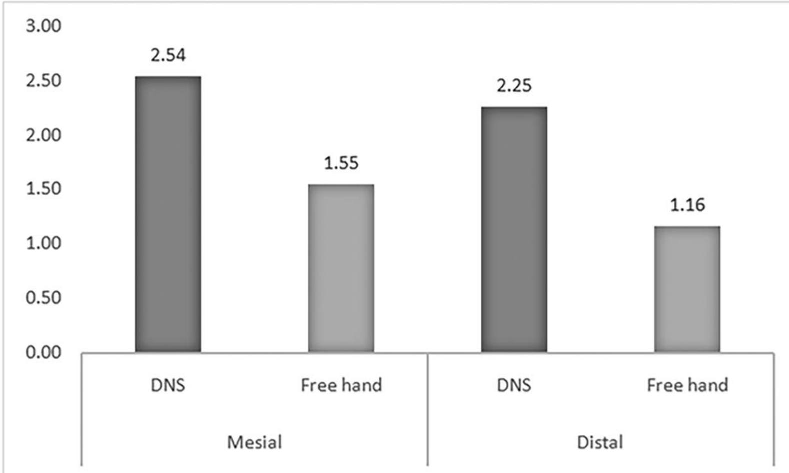

Figure 5. Mesial and distal proximity of roots to IZC screw position comparison (independent *t*-test).

statistical significance ($P < .053$). Tahmaseb et al.[3] reported that navigational systems improved apex accuracy, although apex deviations were less significant compared to the entry point. This may be due to minor cumulative angular errors that become more pronounced at deeper anatomical levels. Block et al.[13] supported this, noting that, although apex accuracy improved with dynamic navigation, it is often the angular control throughout the drilling process that plays a more critical role in overall accuracy. Additional support came from Schneider et al.,[14] who found that deviations at the apex, while reduced, can be influenced by factors such as bone density and drill deflection during implant placement. This study echoed results from studies like Aydemir et al.,[9] in which dynamic navigation significantly reduced angular deviations.

Angular Deviation

The significant reduction in total angular deviation (7.65° less with dynamic navigation, $P < .003$) was in agreement with previous findings in the literature. Block et al.[13] demonstrated that dynamic navigation significantly decreased angular deviations, which are critical for ensuring the proper axis of the implant relative to surrounding anatomical structures. Tahmaseb et al.[3] noted that angular deviations in freehand techniques were one of the primary sources of implant malposition, which dynamic navigation effectively mitigates. Additionally, Widmann et al.[6] observed that navigation systems provided real-time positional data, enabling more accurate corrections in angulation during the drilling and implant placement process.

Postoperative Stability and Clinical Outcomes

No cases of implant loosening were observed postoperatively in this study, suggesting that dynamic navigation may contribute to improved clinical stability. This finding was in agreement with D'Haese et al.,[12] who reported high postoperative success rates with dynamic navigation, largely due to its ability to ensure accurate placement and angulation. Verhamme et al.[11] suggested that accurate placement directly correlated with higher primary stability, reducing the risk of postoperative complications such as implant loosening. Additionally, Zwinger et al.[15] highlighted the long-term benefits of navigation-assisted implant placement, including reduced rate of complication and higher survival rate of the implants over time. Future advancements in image registration and CBCT technology may further enhance the precision of DN systems, minimizing human error and improving the outcomes for orthodontic implant placement.

Deguchi et al.[16] reported that miniscrews in the maxilla had a considerably greater success rate than those in the mandible ($P < .001$), with 96.3% for category I screws. Approximately 50% of the miniscrews were placed appropriately distant from the roots, whereas 25% were close, indicating a risk of failure. Because of the lesser root proximity, miniscrew placement was successful in the maxillary premolar area 95% of the time. In the present investigation, IZC screws inserted using dynamic navigation were further from the roots because they were closer to the planned position than those placed freehand, which is a method that is tactile and arbitrary.

Study Limitations

Due to the nontrivial surgical implementation, dynamic navigation requires intensive training for success. Consistent deviation-free implant placement was not possible even with sophisticated instruments and mean linear deviations exceeded the planned position values. Surgical costs are higher than with traditional methods. Interoperator bias comparisons were not made in this study since a single operator placed all the IZC screws, ensuring that differences in implant placement were purely due to the insertion technique rather than differences in skill level. Planning bias could be prevented if planning and placement are done by the same investigator and soft tissue retraction could be challenging, since IZC screws are positioned more posteriorly, which may restrict accessibility. Future studies should increase the sample size for better accuracy in placement and lesser deviations.

CONCLUSIONS

- Potential for real-time adjustments during implant placement with the dynamic navigation system could be particularly advantageous in orthodontic applications where precision in infrazygomatic screw placement is crucial.
- Dynamic navigation decreased the entry and angular deviations compared to the freehand method.
- Dynamic navigation decreased the linear and angular deviations by approximately 1.93 mm and 7.60°, respectively, in screw positioning.
- Implants placed with dynamic navigation and those placed freehand both had good survival rates.

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