RESEARCH PAPER

Comparative Evaluation of Accuracy Between Dynamic and Hybrid Navigation Systems in Dental Implant Placement

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ABSTRACT

Background:

The precision of implant surgery is crucial for long-term clinical success. Conventional freehand implant placement, though widely practiced, is limited by operator dependency and reduced accuracy. To enhance precision, navigation-guided systems have been developed. Dynamic navigation offers real-time 3D visualization for accurate implant positioning, while hybrid navigation integrates static and dynamic guidance, combining pre-planned precision with intraoperative adaptability. This study aims to evaluate and compare the accuracy of implant placement using dynamic navigation (DN) and hybrid dynamic navigation techniques.

Materials and Methods:

Thirty subjects requiring implant placement in the upper maxillary region were randomly assigned into two groups: Group 1 – Dynamic Navigation (n = 15) and Group 2 – Hybrid Navigation (n = 15). Preoperative implant planning was performed using cone beam computed tomography (CBCT) data in DICOM format and intraoral scan data in STL format. Surgeries were executed using Navident software (Claronav, Canada). The hybrid group utilized dynamic navigation with a thermoplastic stent to enhance precision. Postoperative accuracy was evaluated by merging preoperative and postoperative CBCT data using Evalunav software. Parameters compared between groups included mesiodistal, buccolingual, and apical deviations (distance and angulation), as well as inter-implant distances.

Results:

Hybrid navigation showed significantly lower mean deviations in mesiodistal, buccolingual, and apical positions compared to dynamic navigation alone ($p < 0.05$). Angular deviation was also reduced, indicating improved precision and control during implant placement.

Conclusion:

Hybrid navigation enhances implant placement accuracy by combining static stent stability with real-time dynamic guidance, reducing operator-dependent errors and improving clinical outcomes.

Keywords: Dental Implants, dynamic navigation, parallel implants, haptic feedback, accuracy

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INTRODUCTION

Dental implant placement has become one of the most sought-after procedures in modern dentistry, thanks to improvements in materials, imaging and digital workflows. Initially, the introduction of cone-beam computed tomography (CBCT) revolutionised treatment planning by offering three-dimensional imaging for precise assessments of alveolar bone morphology, adjacent anatomical structures and prosthetic considerations. (1) This advancement paved the way for static implant-guided techniques, commonly referred to as static navigation, which rely on pre-planned surgical guides to position and direct drilling for implants. Static navigation utilises CBCT data and intraoral scan (STL) data to design 3D-printed surgical guides that control the drill's entry point, angulation and depth during implant placement (1,2). Static guides offer high accuracy in controlled settings, they have inherent limitations: they are entirely reliant on pre-planned trajectories, and any unexpected intra-operative anatomical variation (for example, bone irregularity, soft tissue constraints or limited access) cannot be easily addressed without abandoning or modifying the guide. Moreover, potential issues such as guide misfit, displacement or deviation from the planned path may compromise surgical outcomes.

Dynamic navigation addresses many of these shortcomings by offering real-time computer-assisted guidance during surgery. This method integrates preoperative CBCT data with intraoperative tracking of the drill and patient, allowing the clinician to visualise and adjust the orientation of the implant drill on a monitor during surgery (3,4). Originally developed for neurosurgery, orthopaedics and oncology, dynamic navigation has proven increasingly effective in dental implantology. [5] Studies show that dynamic navigation permits safe implant placement, especially in minimally invasive or flapless procedures, and may reduce operator-dependent variability. [36] However, dynamic navigation systems are not without limitations: they require meticulous setup and registration, may have a steep learning curve for surgeons, and lack the inherent physical stability of a template or guide to control the drill's path rigidly.

Recognising the strengths and weaknesses of both approaches, a hybrid navigation technique is introduced as a novel solution in implant surgery. Hybrid navigation combines the pre-planned precision and stability of a static surgical guide for initial drill position and trajectory, with the intraoperative adaptability of dynamic navigation. In this workflow, the static guide ensures accurate entry and angulation during initial drilling, while the dynamic navigation system provides continuous feedback and allows intra-operative corrections if anatomical variations or unforeseen challenges arise. (5,6) This synergy can improve safety, accuracy and efficiency, particularly in complex clinical scenarios such as narrow alveolar ridges, irregular bone anatomy, or placement in proximity to critical structures like the maxillary sinus or inferior alveolar nerve. In aesthetic zones, where even minor deviations in implant positioning can have significant prosthetic and aesthetic consequences, hybrid navigation offers a strategic advantage (7-9).

While numerous studies have highlighted the use and accuracy of dynamic navigation in dental implantology, few have addressed hybrid navigation workflows (10,11). Thus, the comparative effectiveness of hybrid versus standalone dynamic navigation remains underexplored. The present study aims to compare hybrid and dynamic navigation systems in implant placement, in order to evaluate clinical accuracy, efficiency and overall treatment outcomes.

MATERIALS AND METHODS

Study Design

A total of 30 patients in need of adjacent dental implants in the posterior region sought treatment at the Department of Implantology, Saveetha Dental College and Hospital in Chennai, between October 2023 and April 2024. These participants were systematically allocated into two groups: the dynamic navigation group (Group 1, n = 15) and the hybrid navigation group (Group 2, n = 15). The study included both male and female participants, with Group 1 consisting of 8 males and 7 females, while Group 2 comprised 7 males and 8 females. To ensure a balanced demographic distribution, patients were further categorized into four age groups: 18–25 years (Group 1), 25–35 years (Group 2), 35–45 years (Group 3), and 45–55 years (Group 4). Written informed consent was obtained from all participants before the study began, in accordance with the principles of the Helsinki Declaration. Participants were recruited consecutively from those scheduled for implant surgery.

The aim of this randomized, controlled clinical study was to evaluate the differences in the actual implant position following dynamic and hybrid implant placement. The primary outcomes included Apex, Apex in 3D, Mesiodistal and Angulation deviation between the intended and actual implant positions. Inter-implant distance was considered the secondary outcome.

Inclusion and Exclusion Criteria

A single operator carried out the screening of the patients that participated in the study and evaluated the inclusion and exclusion criteria.

The inclusion criteria were as follows:

i. Participants must be at least 18 years old and in good health;
ii. Teeth that cannot be preserved due to causes unrelated to periodontitis, such as fractures, endodontic complications, or root resorption;
iii. Absence of localized infection;
iv. Missing adjacent teeth.

The exclusion criteria were as follows:

(i) General contraindications to oral implant surgery, such as immunodeficiency or long-term corticosteroid usage

(ii) Disorders or therapies that alter bone tissue metabolism, such as local irradiation or bisphosphonates

(iii) History of periodontitis or untreated periodontitis in the adjacent teeth.

(iv) Heavy smokers or those who have smoked heavily in the past and quit within the last five years or more than twenty cigarettes a day.

Sample Size

The sample size for this study was determined based on the parent article, *Comparative Evaluation of Accuracy of Adjacent Parallel Implant Placements Between Dynamic Navigation and Static Guide: A Prospective Study*, and further supported by findings from a recent study on navigation precision in implantology [3]. The calculation was performed using G*Power software (version 3.1, Düsseldorf, Germany), ensuring a statistical power of 80% and a significance level (α) of 0.05 to achieve adequate reliability and validity of the results.

Randomization

Randomization was conducted on a first-come, first-served basis, with the first 15 patients assigned to the dynamic navigation group and the subsequent 15 patients placed in the hybrid navigation group. (IBM SPSS Statistics, version 23.0; SPSS Inc., Chicago, USA). To ensure allocation concealment, an independent investigator—who was not involved in subsequent procedures or assessments—secured the assignments in opaque, sealed envelopes. Participants in both the hybrid and dynamic navigation implant placement groups were randomly assigned. While it was not possible to blind either the participants or the surgeons during treatment, the outcome assessor remained unaware of the group allocations.

Prosthetically Guided Digital Implant Planning: Group 1:

The patients requiring adjacent/ parallel implants were included in this study. All the patients regardless of the group were subjected to CBCT analysis (*CareStream 9600, Onex Corporation, Rochester, New York, United States*) and intra oral scan. The DICOM data (Digital Imaging and Communication in Medicine) and the STL (Standard Tessellation Language) files were uploaded into the Dynamic navigation software for prosthetically driven implant planning. The Dynamic navigation software used in this study was Navident (*Claronav, Canada*). The DICOM data and the STL files were merged using three-point alignment within the software. The virtual mock-up of the missing teeth were carried out and the three-dimensional position of the tooth was verified by the operator. Corresponding to the tooth position, the implant of proper dimensions are chosen and virtually planned with the software.

Group 2: Fabrication of Stent

In Group 2, the stent was fabricated by obtaining the STL file from the Navident EvaluNav software, which was then merged with the 3Shape implant planning software to verify implant positioning. The finalized file was subsequently exported to the DIO Probo 3D printer for guide fabrication.

Implant Placement Under dynamic navigation

Calibration and registration procedures were performed before the surgery. The computer was able to assess the relationship between drill position and actual anatomical structures through calibration of each drill prior to drilling, which also established the relationship between the surgical handpiece and the patient monitoring jaw tracker. The constant jaw movements were noted constantly with the help of jaw trackers placed in the patient's jaw. As all the performed cases were maxillary posteriors, head tracker was adapted as depicted in Figure 3(A) . Handpieces were connected with the drill tags that had the optical sensors which were constantly detected by stereo cameras illuminated by the LED light panel. Trace points were selected on the adjacent teeth on the CBCT loaded to the software, the trace registration was carried out by painting the tooth surface with the calibration tip/stylus provided separately. Once the trace registration was complete, the accuracy of the trace registration was assessed by replacing the stylus on to the tooth surface and the software specifies the accuracy**.**

Local anaesthesia was administered, and the drilling sequence was carried out following the manufacturer's recommended procedure. The implant was then placed using a dynamic approach as depicted in Figure 1(A, B). The osteotomy site was prepped keeping in mind the virtual plan guide, and either a tapered bone level implant was placed in an effort to replicate the digitally intended position. A healing cap was placed. The cover screw was positioned for all cases, primary stability of 30 Ncm was achieved for all the cases. Subsequently, the incisions were sutured using 3.0 silk non-absorbable simple interrupted sutures.

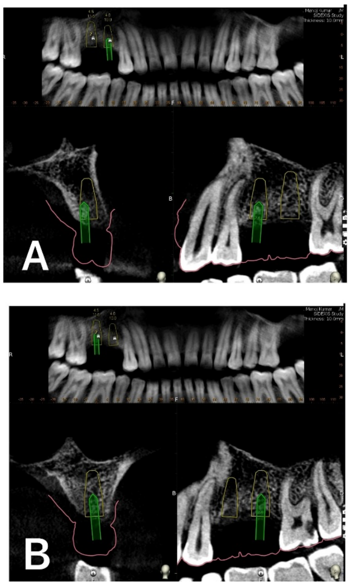

Figure 1: (A) shows implant placement with respect to tooth 15 performed under dynamic navigation guidance. (B) depicts implant placement with respect to tooth 16 using dynamic navigation.

Dynamic navigation works through the triangulation procedure where the LED light panel illuminates the optical sensors that are present in the jaw tracker attached to the patient's jaw, drill tag attached to the surgical handpiece. While looking at a screen, the osteotomy site was prepared, the implant was inserted, and further procedures were performed with the patient's mouth visible to guarantee accurate implant placement. This procedure has a steep learning curve associated with it and the surgeon has to adapt to the haptic feedback mechanism.[11]

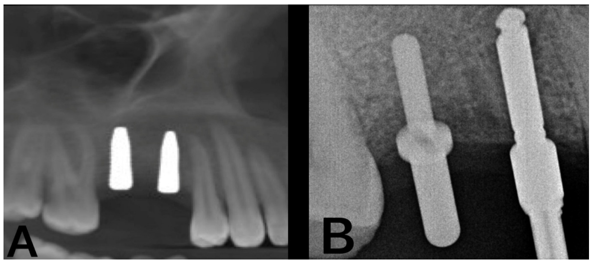

Figure 2: (A) shows the radiographic view of implant placement in relation to teeth 15 and 16. (B) illustrates the implant position indicator (PID) used during radiographic evaluation.

Implant Placement Under hybrid navigation

In the hybrid navigation group, the procedure was conducted following the same steps as in Group 1 (dynamic navigation), with the sole distinction being the incorporation of a stent in this group as depicted in Figure 3(B).

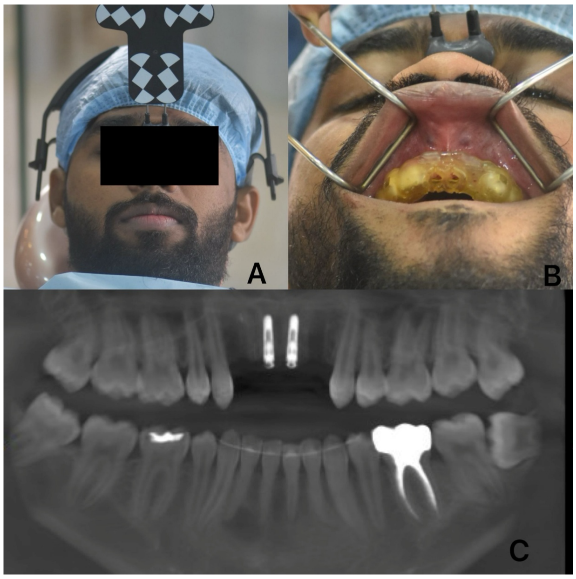

Figure 3: (A) Patient set-up with dynamic navigation tracking marker, (B) stent positioned intraorally for guided implant placement, (C) postoperative radiograph confirming accurate adjacent implant positioning.

Outcome Assessment

On the same day following implant placement, the final implant position was assessed using CBCT imaging. This was done by overlapping the pre-surgical planning CBCT with the post-placement CBCT through a built-in feature called EVALUNAV. An independent, calibrated examiner who was unaware of the group allocations utilized the Accuracy Analysis function in the Navident dynamic navigation software to compare the actual implant position with the digital treatment plan.

The measurement process within the software was conducted as follows: The planning data was preloaded into the software, and the post-placement CBCT (DICOM data) was imported. Using a three-point configuration, the post-placement CBCT was aligned with the planning DICOM data. The implant position was then manually identified, and the software analysed the superimposed images to measure positional accuracy.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics version 23. Descriptive statistics, including mean and standard deviation, were used to summarize continuous variables, while frequencies and percentages described categorical data. The Independent Samples t-test was applied to compare mean deviations between the Dynamic and Hybrid navigation groups. A p-value <0.05 was considered statistically significant. Results showed that apex, apex 3D, and mesiodistal deviations were significantly lower in the Hybrid group (p = 0.00), indicating higher accuracy. However, angulation deviation showed no significant difference (p = 0.48), suggesting both systems performed comparably in angular precision during implant placement.

Results

Demographic Variables

A total of 30 patients requiring adjacent dental implants in the posterior region participated in the study conducted at the Department of Implantology, Saveetha Dental College and Hospital, between October 2023 and April 2024. Participants were equally divided into two groups — Dynamic Navigation (Group 1, n = 15) and Hybrid Navigation (Group 2, n = 15).

The Dynamic group comprised 8 males and 7 females, while the Hybrid group included 7 males and 8 females. The mean age of participants was 39.87 ± 13.55 years, with ages ranging between 18 and 55 years. To ensure even demographic distribution, participants were categorized into four age groups as mentioned in (Table 1).

- 18–25 years
- 25–35 years
- 35–45 years
- 45–55 years

Table 1. Demographic distribution of study participants

Demographic Variable	Dynamic Navigation (n = 15)	Hybrid Navigation (n = 15)	Total (N = 30)
Gender			
Male	8 (53.3%)	7 (46.7%)	15 (50%)
Female	7 (46.7%)	8 (53.3%)	15 (50%)
Age Group (years)			
18–25	2 (13.3%)	2 (13.3%)	4 (13.3%)
25–35	4 (26.7%)	3 (20.0%)	7 (23.3%)
35–45	5 (33.3%)	5 (33.3%)	10 (33.3%)
45–55	4 (26.7%)	5 (33.3%)	9 (30.0%)
Mean Age (years)	39.87 ± 13.55	39.87 ± 13.55	39.87 ± 13.55

Accuracy Analysis (Deviation Measurements)

The deviation analysis revealed notable differences between the Dynamic and Hybrid navigation systems. The Hybrid navigation method demonstrated consistently lower mean deviations across all measured parameters, indicating superior accuracy compared to the Dynamic system.

Statistical analysis was performed using independent t-tests, with a significance level set at $p < 0.05$. Results for apex, apex 3D, and mesiodistal deviations showed statistically significant differences (p = 0.00*), whereas angulation deviation differences were not significant (p = 0.48).

(Table 2). Comparison of deviation parameters between Dynamic and Hybrid navigation systems

Parameter	Group	Mean ± SD	p-value
Apex Deviation (°)	Dynamic	2.73 ± 0.87	0.00*
	Hybrid	0.27 ± 0.12	

Apex 3D Displacement (mm)	Dynamic	2.42 ± 1.33	0.00*
	Hybrid	0.39 ± 0.30	
Mesiodistal Deviation (mm)	Dynamic	3.78 ± 1.88	0.00*
	Hybrid	0.41 ± 0.26	
Angulation Deviation (°)	Dynamic	3.88 ± 2.07	0.48
	Hybrid	3.45 ± 1.76	

*Significance level set at $p < 0.05$.

DISCUSSION

The main conclusions of our clinical trial were that, compared to implants placed using dynamic and hybrid techniques, the positional discrepancy was significantly lower with the hybrid approach. Moreover, the improved accuracy in implant placement was achieved without compromising primary implant stability.

In a prospective study by Hamza Younis et al., implant placement accuracy was compared among dynamic navigation, static guides, and freehand techniques in 65 patients. Their CBCT analysis showed that both dynamic and static methods were significantly more accurate than freehand, especially in angular, platform and apical deviations; dynamic navigation had the highest angular accuracy ($p = 0.002$) while depth deviations showed no significant differences between groups (12-15). This aligns with our study in which we used both static (via the hybrid workflow) and dynamic navigation. Dynamic navigation comes with its own shortcomings — for example, the handpiece is heavier due to the optical sensor and trackers; thus use of static guides can help reduce deviations caused by hand-eye coordination limitations.

In a retrospective analysis by Dong Wu et al., 38 implants placed with dynamic navigation and 57 with static surgical guides were compared. They found no significant differences between the two methods in coronal, apical or angular deviations. However, dynamic navigation showed a slightly higher apical deviation in anterior teeth ($p = 0.028$) and better angular accuracy in molars. This supports our observation that although dynamic systems can perform very well, they may still face challenges in certain anatomical zones and benefit from adjunctive stability provided by static guidance (16).

Our findings also align closely with the meta-analysis by Kun Li et al., which compared the accuracy of dynamic computer-aided implant surgery (dCAIS) and static computer-aided implant surgery (sCAIS). In their analysis of nine studies, dCAIS significantly reduced apical and depth deviations compared to sCAIS, although platform and angular deviations showed no statistically significant difference(12,13). Similarly, in this study the dynamic navigation group demonstrated superior accuracy in mesiodistal displacement and angulation, particularly for adjacent parallel placements.(17)

Another comparative study by D. Parekar et al. (DN vs. static guides for adjacent parallel implant placements) reported significantly better mesiodistal accuracy in the dynamic navigation group (0.55 ± 0.56 mm) compared to the static guide group (5.61 ± 3.1 mm). This aligns with our result where dynamic navigation provided improved precision in implant positioning. However, as in our study, the static guide (or the static component of hybrid workflows) was favored for reducing surgical time and improving operator comfort, highlighting that while dynamic navigation enhances accuracy, static guidance offers practical advantages in handling and workflow efficiency(18-21).

Additional literature assessing 3D accuracy of computer-assisted navigation (CAN) systems reported a mean entry point deviation of 0.43 mm and angulation deviation of 4°, with approximately 65% of drills placed within 1 mm of the mandibular canal and 30% perforation rate, underscoring the need for a minimum 1.1 mm safety margin. These results reinforce our findings where dynamic navigation showed superior accuracy in mesiodistal positioning and angulation—especially near critical anatomical structures—reinforcing the value of navigation systems for precise implant placement.(22,23)

Yet, some studies such as by comparing static vs. dynamic CAIS in single-tooth cases involving 60 patients) found no statistically significant differences in platform, apex or angular deviations; the dynamic group however showed a significantly higher mesial deviation ($p = 0.032$). Those results are in line with our observation that while dynamic systems may match or exceed accuracy in many dimensions, static or hybrid approaches may still yield advantages in certain directional deviations.(24).

This study supports the broader evidence that guided implant placement systems (both static and dynamic) yield superior accuracy compared to traditional free-hand techniques; more importantly, our data suggest that a hybrid navigation workflow – combining the mechanical/template stability of static guides with the intraoperative flexibility of dynamic navigation – may deliver the best of both worlds in terms of precision and adaptability.

A major strength of this study is the direct clinical comparison of the hybrid navigation approach with dynamic navigation alone, allowing assessment of both accuracy and clinical applicability in adjacent implant placement. The use of CBCT-based measurements and intra-operative registration strengthens the reliability of deviation analysis.

However, the study is limited by a modest sample size (n = 30) and non-randomised group allocation, which may affect generalisability and introduce selection bias. Being a single-centre study focused on posterior adjacent implants, the findings may not apply to other clinical scenarios. Additionally, operator learning curves and long-term clinical outcomes were not evaluated and warrant further investigation.

The integration of a surgical stent with dynamic navigation improves the precision and predictability of dental implant placement by enhancing control over implant depth and angulation. This hybrid approach is particularly advantageous in anatomically complex and adjacent implant cases, reducing positional errors and improving prosthetic alignment. Although it requires additional planning and training, the technique streamlines surgical workflow and enhances patient safety. Further multicenter studies are required to confirm its clinical effectiveness and cost-efficiency.

CONCLUSION

In accordance with the study aim, the findings demonstrate that hybrid dynamic navigation provides accuracy compared to dynamic navigation alone in dental implant placement. The integration of a surgical stent enhances control over implant positioning, resulting in improved precision and predictability, particularly in complex and adjacent implant cases. Although the technique requires additional planning, it contributes to improved surgical accuracy, streamlined workflow, and enhanced patient safety. Further large-scale clinical studies are recommended to validate these results and assess long-term clinical outcomes and cost-effectiveness.

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