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Comparative Evaluation Of Accuracy Between Various Surface Tracing Techniques Under Dynamic Navigation

Kausthuba Ramesh[1], Sahana Selvaganesh[*2], Thiyaneswaran N[3]

[1]Post Graduate Resident, Saveetha Dental College, Saveetha Institute of Medical & Technical Sciences, Saveetha University, Chennai, India

[2]Assistant Professor, Saveetha Dental College, Saveetha Institute of Medical & Technical Sciences, Saveetha University, Chennai, India

[3]Professor and Head, Department of Implantology, Saveetha Dental College, Saveetha Institute of Medical & Technical Sciences, Saveetha University, Chennai, India

Corresponding Author:

Dr. Sahana Selvaganesh

Assistant Professor, Saveetha Dental College, Saveetha Institute of Medical & Technical Sciences, Saveetha University, Chennai, India

Email ID: sahanas.sdc@saveetha.com

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ABSTRACT

Background: Dynamic navigation systems have enhanced the precision of dental implant placement. However, the necessity of combining intraoral scanning (IOS) with cone-beam computed tomography (CBCT) for improved accuracy remains debatable.

Aim: This study aimed to compare the accuracy of implant placement using CBCT alone versus CBCT combined with IOS under dynamic navigation.

Materials and Methods: A total of 40 dentate patients requiring mandibular posterior implants were randomly divided into two groups. Group 1 underwent implant planning using CBCT and IOS, while Group 2 used CBCT data alone. All surgeries were performed using dynamic navigation (Navident system), and postoperative deviations were assessed using CBCT-based analysis.

Results: Across most anatomical reference points, no statistically significant differences were observed between groups. Statistically significant differences were found only in apex mesiodistal deviation at site 36 (mean+/-SD (N) - 0.28 ± 0.52 (20));(0.28 mm, $p = 0.02$) and apex vertical deviation at site 37 (mean+/-SD (N) - 0.32 ± 0.68 (20)); (0.32 mm, $p = 0.04$); however, these remained within clinically acceptable limits (<0.5 mm).

Conclusion: The addition of IOS to CBCT did not result in significantly improved implant placement accuracy under dynamic navigation, suggesting CBCT alone provides sufficient accuracy in clinical settings.

Keywords: *Dynamic navigation systems, combining intraoral scanning (IOS), cone-beam computed tomography (CBCT)*

1. INTRODUCTION

Implantology is a growing field that helps the patients regain the lost dentition, the popularity associated with the implant therapy is that it closely mimics the natural dentition and gives a natural emergence profile to the edentulous site (Li *et al.*, 2023). Ongoing research over a decade in implantology strives in establishment of implants as close as the natural teeth with working on digital planning to place the implants in the prosthetically correct position to establish more function and esthetics,(Sundaram *et al.*, 2023) various guidance methods to improve the precision in implantology and the material science for improved force distribution and survival in the oral environment (Wang *et al.*, 2024).

When considering implant surgery, patients opt for alternatives that save their time and cost, lower complications, meet their high aesthetic requirements, and provide lasting functionality.(Dotia *et al.*, 2024). It has been demonstrated that the use of navigation leads to precise implant placement.Before a physician decides to use dynamic navigation in his patients, the surgeon must be given adequate reasons for taking this approach and see the benefits of improved accuracy, precision, efficiency, including cost, time savings and ergonomics (Parekar, Selvaganesh and Nesappan, 2024).

A significant breakthrough in computerized virtual implant treatment planning was achieved through development of cone beam computed tomography scanning combined with 3D imaging tools. Cone-beam computed tomography data, when paired with an implant planning software has allowed virtually optimum placements to be planned, with due consideration given to surrounding essential anatomical structures as well as subsequent prosthesis requirements. As a result, the desired virtual implant position will be transferred from the computer to the patient. Moreover, intraoral scanning devices have recently begun to play a significant role in planning these novel treatment modalities (Jaju and Jaju, 2014).

A more realistic digital view of the patient's hard and soft tissues is created by superimposing recognizable structures such as teeth obtained through cone beam CT or intraoral scanning. (Nirula, Selvaganesh and N, 2023). Apart from the IOS, there are additional non-invasive ways for assessing implant placement accuracy. (Chhabra, Selvaganesh and Nesappan, 2023). In the case of implants placed under dynamic navigation, it remains to be determined which method is more accurate. In our opinion, only 2 studies conducted by Skjerven et al (Skjerven *et al.*, 2019) and jan et al (van Hooft *et al.*, 2022) compared IOS to CBCT as a method for implant placement accuracy in vivo post operatively. They have validated IOS as an alternative to CBCT for determining placement accuracy postoperatively (van Hooft *et al.*, 2022).

Thus, the aim of this prospective clinical case series was to determine whether IOS is a necessity along with CBCT to determine dental implant placement accuracy preoperatively in an in vivo setting and to describe deviations between both methods.

2. MATERIALS AND METHODS:

2.1. Patient Selection:

This study was carried out in the department of implantology, Saveetha Dental college, the study was approved by the institutional review board.. A total of 40 dentate patients, referred to the department of implantology for rehabilitation of the mandibular posteriors with dental implants, were enrolled in this study. Patients were excluded if they were suffering from active periodontal disease, severe bruxism, or under chronic systemic disorders.. All patients provided written informed consent.

2.2. Preoperative Data Acquisition:

Patients were divided and randomly allocated into two groups. Post clinical examination , Group 1 patients were subjected to CBCT (Cone beam computed tomography) and intra oral scanning, Group 2 patients were subjected to CBCT alone.

2.3 Virtual Implant Planning:

In group 1 :CBCT data is taken and uploaded into Navident software and in group 2 : Pre-op DICOM files and the IOS were uploaded in the navident software and both were merged together with 3 point alignment. The prosthetic positioning of the implant was decided using "addcrown" mode in the navident planning software. The ideal implant location was determined, maintaining a safety margin relative to vital anatomical structures of 1.5 mm.

2.4. Implant Placement:

On the day of surgery the patient was prepared and the navident unit was oriented to the operation theatre environment using R-fine calibration. The patients were fitted with a jaw tracker and a head tracker depending on the implant site. The calibration process for group 1 was done by selecting 3 points on the CBCT and trace registration was carried out using a tracer with a stylus tip. In group 2 the calibration process was done by selecting 3 points of the STL file. The accuracy of merging the real time patient data with the CBCT/STL file was noted by keeping the stylus tip at particular points that were taken into consideration in the study. Surgery was performed under local anesthesia using appropriate aseptic and sterile protocols. Osteotomies were prepared at a maximum of 800 rpm and guided in real time by indicating the desired drilling pathway on the computer screen. An extra calibration process was completed preceding the use of each new drill. Prior to the preparation of the implant placement, no punching of the gingival tissues was performed. implants were installed. All implants were placed by the same operator who was not involved in data collection and analysis. Post implant placement the accuracy of the planned and placed positions were noted using the inbuilt Navident software called EVALUNAV.

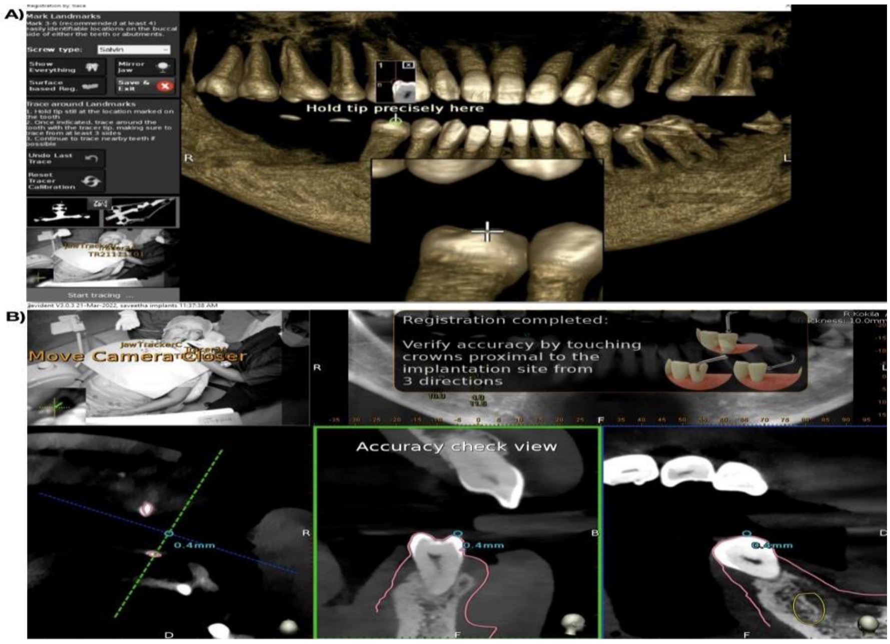

FIG 1 (a) : ORIENTATION AND TRACE REGISTRATION USING CBCT ALONE ; (b) ORIENTATION AND TRACE REGISTRATION USING STL FILE

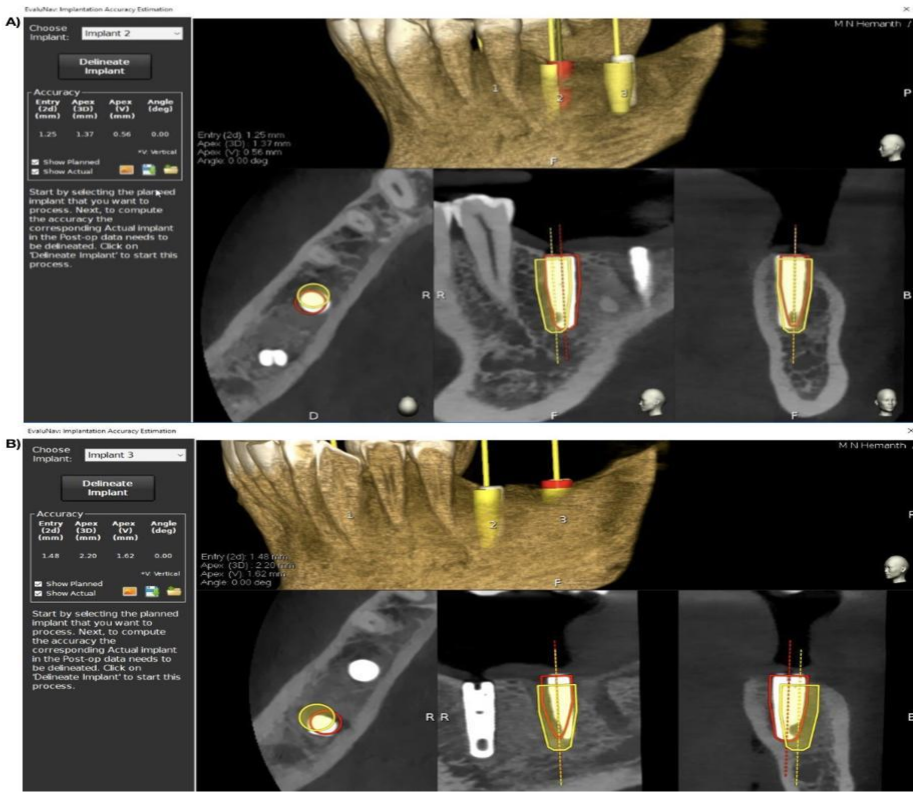

FIG 2 (a) : ACCURACY ANALYSIS POST IMPLANT PLACEMENT USING EVALUNAV FOR GROUP 1; (b) ACCURACY ANALYSIS POST IMPLANT PLACEMENT USING EVALUNAV FOR GROUP 2

3. RESULTS

According to the two techniques of trace registration, one using CBCT and the other using STL files, there was no statistically significant difference in the accuracy assessment in specific teeth 35, 45 ,33 and 43. There was no significant difference in the two methods of trace registration in relation to accuracy analysis on various points on tooth 35. There was a statistically significant difference in the mid palatal point during accuracy analysis in tooth 45., with CBCT being more accurate than the STL tracing (Table 1).

35	**COMPARISON BETWEEN GROUPS**	**Mean ± SD (N)**	**significance**
	Buccal cusp tip	-0.02 ± 0.40 (20)	0.78
	Palatal cusp tip	-0.07 ± 0.42 (20)	0.43
	Mid facial	-0.04 ± 0.46 (20)	0.67
	Mid palatal	-0.16 ± 0.53 (20)	0.18
	Facial crevicular	0.02 ± 0.24 (20)	0.65
	Palatal crevicular	-0.10 ± 0.39 (20)	0.25
45	**COMPARISON BETWEEN GROUPS**	**Mean ± SD (N)**	**significance**
	Buccal cusp tip	-0.03 ± 0.30 (20)	0.61
	Palatal cusp tip	-0.01 ± 0.25 (20)	0.86
	Mid facial	-0.15 ± 0.35 (20)	0.07
	Mid palatal	-0.23 ± 0.28 (20)	0.05*
	Facial crevicular	0.01 ± 0.29(20)	0.87
	Palatal crevicular	-0.09 ± 0.35 (20)	0.23

Table 1: Table 1 represents the accuracy at different points on the tooth surface in relation to tooth 35 and 45 comparing group 1 and group 2

The same accuracy analysis was carried out on the tooth numbers 33, 43. There was no statistically significant difference in the tooth 33 and 43 (Table 2)

33	COMPARISON BETWEEN GROUPS	mean+/-SD (N)	Significance
	Mesial cusp tip	-0.08 ± 0.26 (20)	0.15
	Distal cusp tip	-0.07 ± 0.39 (20)	0.48

	Mid facial	-0.01 ± 0.34 (20)	0.88
	Mid palatal	0.03 ± 0.27 (20)	0.55
	Facial crevicular	-0.05 ± 0.33 (20)	0.43
	Palatal crevicular	-0.03 ± 0.27 (20)	0.58
43	COMPARISON BETWEEN GROUPS	Mean ± SD (N)	Significance
	Mesial cusp tip	-0.08 ± 0.36 (20)	0.39
	Distal cusp tip	-0.22 ± 0.40 (20)	0.08
	Mid facial	0.03 ± 0.34 (20)	0.67
	Mid palatal	-0.12 ± 0.41 (20)	0.25
	Facial crevicular	-0.03 ± 0.37 (20)	0.74
	Palatal crevicular	-0.09 ± 0.33 (20)	0.23

Table 2 : Table 2 represents the accuracy at different points on the tooth surface in relation to tooth 33 and 43 comparing group 1 and group 2

Post implant placement accuracy was evaluated using EVALUNAV software and comparison between group 1 and group 2 indicated that there was statistically significant difference in the Apex deviation alone where group 1 had a lesser deviation (0.17±0.4 mm) with p value <0.05 in relation to implant placed in 36. There was no statistically significant difference in the accuracy of implant placement between the groups with relation to implant placement in 37 (Table 3).

36	COMPARISON BETWEEN GROUPS	mean+/-SD (N)	significance
	Entry(mm)	0.106 ± 0.49 (20)	0.35
	Apex(md deviation)	0.28 ± 0.52 (20)	0.02*
	Apex (vertical) mm	0.05 ± 0.57 (20)	0.67
	Angulation(degree)	0.29 ± 0.68 (20)	0.07
37	COMPARISON BETWEEN GROUPS	Mean ± SD (N)	significance

	Entry(mm)	0.02 ± 0.65 (20)	0.85
	Apex(md deviation)	0.14 ± 0.54 (20)	0.23
	Apex (vertical) mm	0.32 ± 0.68 (20)	0.04*
	Angulation(degree)	-0.2 ± 0.68 (20)	0.2

Table 3 : Table 3 represents the accuracy at different points on the tooth surface in relation to tooth 36 and 37 comparing group 1 and group 2

4. DISCUSSION

In dynamic navigation for dental implant placement, the integration of an intraoral scanner (IOS) with cone-beam computed tomography (CBCT) is essential for enhancing the accuracy of trace registration . While CBCT provides a detailed 3D representation of the patient's anatomy, it lacks the precision in capturing the surface details of the oral cavity, which are crucial for accurate registration and alignment during navigation (Knipper *et al.*, 2024). The IOS complements CBCT by offering highly accurate surface scans of the dentition and soft tissues, which serve as reference points in the trace registration process. This dual-modality approach ensures that the virtual plan is more precisely aligned with the actual intraoral environment, reducing the risk of deviations and improving the overall accuracy of implant placement(Han *et al.*, 2024) .

The present prospective clinical study aimed to evaluate the comparative accuracy of implant placement when planned using CBCT alone versus CBCT combined with IOS under dynamic navigation. Across multiple anatomical reference points and implant sites, our findings consistently demonstrated that there were no statistically significant differences between the two groups in most measured parameters, with few exceptions.

CBCT and IOS validation methods displayed a mean absolute deviation, when compared between the two groups there was no significant difference between them , the exception being the mid palatal cusp of 45 , which showed statistical difference . This falls in line with the other recent literature regarding the implant placement accuracy of dynamic guided implant surgery.

To analyze deviations in 3D between IOS and CBCT scans, one could suffice with only calculating the differences between the achieved implant locations between these and only calculating the differences between achieved implant locations between the two imaging types. Since the surface contours on the buccal,lingual, medial,distal aspects are also clinically relevant, accuracy immediately after trace registration with the tracer tip was checked. Previous studies have used intraoral scans and merged the scan data to assess the deviations post operative , whereas we have used just the CBCT data to assess the pre and post operative placements . The trace registration aspect in our study is restricted to CBCT alone for one group and CBCT and IOS for another group.

Once trace registration was carried out for group one and group two, implant placements were carried out and post placement deviations were assessed using Evalnav. These post placement deviations are crucial parameters to assess whether the trace registration done was accurate. When group 1 and group 2 were compared in Evalnav, there was a significant difference only in the apex deviations (mesiodistal and vertical deviations seen) .

The apex deviation is a crucial factor in assessing the accuracy of these methods , but these values also depend on the quality of CBCT loaded and merging the pre and post CBCT can also hamper the values if their quality is compromised.

In group 1 (CBCT and IOS) the mean deviation was 0.15 +/- and in group 2 (CBCT only) the mean deviation was 0.48 +/- . This could be due to surgeons surgical skills as these are confounding factors.

At the 36 and 37 implant sites, where key parameters like entry point deviation, apex deviation (mesiodistal and vertical), and angulation were assessed, results showed marginal deviations between the groups. Notably, apex mesiodistal deviation at the 36 region (mean deviation: 0.28 mm, $p = 0.02$) and apex vertical deviation at the 37 region (mean deviation: 0.32 mm, $p = 0.04$) displayed statistically significant differences. However, despite statistical significance, the magnitude of deviation remained within clinically acceptable limits (<0.5 mm), suggesting negligible clinical impact on implant success or prosthetic outcome.

For other evaluated points, including the buccal and palatal cusp tips, mid-facial and mid-palatal positions, and crevicular margins at the 33, 35, 43, and 45 sites, no significant differences were observed. This consistency across multiple sites further supports dynamic navigation in facilitating accurate implant placement regardless of whether IOS data were integrated alongside CBCT.

These findings align with prior literature. Skjerven et al (Skjerven *et al.*, 2019). and Jan et al (van Hooft *et al.*, 2022) have previously validated IOS as a comparable alternative to CBCT in post-operative implant accuracy assessment. Our results corroborate their conclusions, suggesting that the addition of IOS may offer supplementary visualization benefits but does not drastically enhance placement accuracy under dynamic navigation in a clinical setting. Moreover, the minimal deviations observed in both groups reinforce the effectiveness of dynamic navigation systems in achieving predictable outcomes.

While IOS undeniably offers advantages in terms of patient comfort, soft tissue visualization, and digital workflow integration, the data suggest that its impact on accuracy, specifically in the context of dynamic navigation, may not be critical (Dolidze, Kublashvili and Iantbelidze, 2025). However, the clinical decision to include IOS may still be justified based on broader prosthetic planning, particularly when aiming to harmonize soft tissue contours and emergence profiles.

5. CONCLUSION

In conclusion, within the parameters of this study, the combination of CBCT and IOS did not significantly outperform CBCT alone in terms of implant placement accuracy under dynamic navigation, except for minor deviations at select posterior sites. These deviations, however, remained within clinically acceptable limits. Dynamic navigation appears to offer high accuracy regardless of the surface tracing method employed, supporting its utility in contemporary implantology.

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