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Safe and Accurate Immediate Implant Placement in the Posterior Maxilla: The Role of Dynamic Navigation in Transcrestal Sinus Augmentation

PhD Thesis

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PUBLICATIONS PROVIDING THE BASIS OF THE THESIS

Jain S, Solanki A. A dynamic surgical navigational approach for immediate implantation and transcrestal sinus augmentation. *J Indian Soc Periodontol*. 2021;25(5):451-6. doi:10.4103/jisp.jisp_581_20

SJR rank: Q2

Jain S, Nagy K, Bhalerao A. Accuracy and safety of dynamic navigation vs. freehand approach in indirect sinus lift and immediate implant placement: A split-mouth clinical study. *J Dent*. 2025;160:105866. doi:10.1016/j.jdent.2025.105866

SJR rank: Q1/D1

ABBREVIATIONS

CBCT	Cone Beam Computed Tomography
DICOM	Digital Imaging and Communications in Medicine
DN	Dynamic Navigation
OD	Osseodensification
VAS	Visual Analog Scale

I. INTRODUCTION

Dental implant therapy has become a predictable and widely accepted treatment modality for the rehabilitation of partially edentulous patients. The long-term success of implant-supported restorations depends on accurate three-dimensional implant positioning, sufficient primary stability, and the preservation of surrounding anatomical structures. These requirements are particularly challenging in the posterior maxilla, where reduced bone height, low bone density, and proximity to the maxillary sinus frequently complicate implant placement.

Following tooth loss, the posterior maxilla undergoes progressive alveolar bone resorption combined with sinus pneumatization, often resulting in insufficient vertical bone height for conventional implant placement. To address this limitation, sinus floor elevation techniques were introduced and have since become an integral part of implant dentistry. While the lateral window approach provides predictable vertical augmentation, it is associated with increased surgical morbidity and a higher risk of complications. Consequently, less invasive transcrestal sinus elevation techniques were developed, offering reduced patient morbidity and shorter treatment times in appropriately selected cases.

More recently, transcrestal sinus elevation has evolved toward graftless approaches combined with immediate implant placement, provided that adequate primary stability can be achieved. Osseodensification (OD) represents a further refinement of this concept. By compacting trabecular bone rather than removing it, OD

enhances primary stability and may facilitate controlled elevation of the sinus membrane through the osteotomy site. This biologically oriented approach has gained increasing attention as a minimally invasive alternative in the posterior maxilla.

In parallel with surgical innovations, advances in digital imaging and computer-assisted technologies have transformed implant planning and execution. Computer-assisted implant surgery aims to transfer a prosthetically driven virtual plan accurately to the clinical setting. Static guidance systems have demonstrated improved accuracy compared with freehand placement but are limited by their lack of intraoperative flexibility. Dynamic navigation (DN) systems overcome this limitation by providing real-time feedback on instrument position relative to the planned implant trajectory, allowing continuous adjustment during surgery.

The potential advantages of DN are particularly relevant in anatomically demanding procedures such as transcrestal sinus augmentation and immediate implant placement, where millimetric deviations may result in membrane perforation or compromised implant positioning. Although growing evidence supports the accuracy of DN compared with freehand techniques, its integration with biologically optimized osteotomy preparation methods, such as OD, has been only sparsely investigated in clinical settings.

Against this background, the present doctoral work focuses on the combined use of DN and OD in transcrestal sinus augmentation with immediate implant placement in the posterior maxilla.

II. OBJECTIVES

The objective of this doctoral work was to evaluate the feasibility, accuracy, and clinical safety of DN in transcrestal sinus augmentation with immediate implant placement in the posterior maxilla. The research was designed to investigate this topic through a staged approach. First, a clinical case study was conducted to demonstrate the practical feasibility of integrating DN with OD-assisted transcrestal sinus elevation and immediate implant placement, and to describe the key surgical and digital steps of this workflow. Subsequently, a randomized split-mouth clinical study was conducted to compare the accuracy and safety of DN-assisted implant placement with the conventional freehand approach in indirect sinus lift procedures with immediate implantation. Together, these investigations were intended to provide both proof-of-concept evidence and controlled clinical data on the role of DN in improving precision and safety during implant placement in the anatomically challenging posterior maxilla.

III. METHODS

III.1. Methods of the Case Study

The first part of this doctoral work was designed as a clinical case study to explore the feasibility of integrating DN with OD-assisted transcrestal sinus augmentation and immediate implant placement in the posterior maxilla. A systemically healthy patient requiring implant rehabilitation in the posterior maxilla was selected following clinical and radiographic assessment. Preoperative three-dimensional imaging was used for prosthetically driven implant planning, with particular attention to residual bone height, sinus anatomy, and implant positioning relative to the planned restoration.

DN was employed to transfer the virtual plan to the clinical setting. Registration and calibration procedures were performed to allow real-time visualization of instrument position during surgery. Implant osteotomy preparation and transcrestal sinus elevation were carried out using OD burs under navigational guidance, followed by immediate implant placement according to the planned trajectory and depth. The case study focused on describing the digital workflow, surgical execution, and intraoperative control achieved with this combined approach, thereby serving as a proof of concept for subsequent clinical investigation.

III.2. Methods of the Randomized Clinical Study

Building upon the experience gained from the case study, a randomized split-mouth clinical study was designed and carried out to evaluate the accuracy and safety of DN in comparison with the conventional freehand approach during indirect sinus lift procedures with immediate implant placement. Systemically healthy adult patients requiring bilateral implant placement in the posterior maxilla were enrolled according to predefined inclusion and exclusion criteria. A split-mouth design was applied, with each patient serving as their own control: one posterior maxillary site was treated using DN, while the contralateral site was treated using the freehand technique.

For all implant sites, preoperative and postoperative three-dimensional imaging was performed using cone-beam computed tomography (CBCT) with standardized exposure parameters. DICOM datasets were imported into DN software (Navident, ClaroNav Technology Inc., Toronto, Canada) for prosthetically driven virtual implant planning. Planning took into account residual bone height, sinus anatomy, and the spatial relationship to adjacent and opposing dentition. In the dynamically navigated arm, the virtual plan was transferred to the clinical setting using real-time navigation with optical tracking and trace-based registration, allowing continuous visualization of instrument position and trajectory during osteotomy preparation and implant placement. In the freehand arm, implant positioning relied on conventional clinical assessment and radiographic guidance without navigational assistance.

In both study arms, osteotomy preparation and indirect sinus elevation were performed using OD burs (Versah, LLC, Jackson, MI, USA) following the same densifying protocol, in order to isolate the effect of navigation on implant positioning. Immediate implant placement was carried out according to the respective planning and guidance method assigned to each study arm.

Postoperative CBCT imaging was obtained for all implants to assess placement accuracy by superimposing planned and achieved implant positions. Accuracy outcomes included linear deviations at the coronal entry point and apical endpoint, as well as angular deviation between the planned and placed implants. Additional outcome measures comprised total procedural time, patient-reported satisfaction assessed using a visual analogue scale (VAS), and the incidence of intraoperative or postoperative complications. This methodological framework allowed a controlled evaluation of DN within a standardized clinical workflow for transcrestal sinus augmentation and immediate implant placement.

IV. RESULTS

IV.1. Results of the Case Study

The case study was completed without intraoperative or postoperative complications. Transcrestal sinus augmentation and immediate implant placement were successfully performed under DN guidance, and stable primary implant fixation was achieved at the planned position. No Schneiderian membrane perforation occurred during osteotomy preparation or sinus elevation.

Postoperative three-dimensional imaging demonstrated close correspondence between the planned and achieved implant positions. The implant remained fully contained within the available bone envelope, with controlled elevation of the sinus membrane and no evidence of cortical or sinus wall violation. The case study confirmed the technical feasibility of combining DN with OD-assisted transcrestal sinus augmentation and immediate implant placement.

IV.2. Results of the Randomized Clinical Study

Twenty-eight patients requiring bilateral indirect sinus lift procedures with immediate implant placement in the posterior maxilla were enrolled, yielding 64 implant sites. Two implants were excluded due to protocol deviations, resulting in 62 implants included in the final analysis. All patients completed the study, and no dropouts were recorded.

Accuracy analysis revealed significantly lower deviations for implants placed using DN compared with the freehand approach. The mean deviation at the entry point was 1.51 ± 0.43 mm in the dynamically navigated arm and 2.69 ± 0.51 mm in the freehand arm ($p < 0.0001$). Mean angular deviation was 2.77 ± 0.63° for dynamically guided implants and 11.09 ± 3.39° for freehand placement ($p < 0.0001$). Mean deviation at the implant apex was 2.72 ± 0.67 mm in the navigation arm compared with 3.91 ± 0.89 mm in the freehand arm ($p < 0.0001$).

Analysis of secondary outcomes showed that the mean procedural time was slightly longer in the dynamically navigated arm, measuring 37.43 ± 7.01 minutes, compared with 34.04 ± 6.65 minutes in the freehand arm ($p < 0.0001$). Patient-reported satisfaction, assessed using a 10-point VAS, was higher in the navigation arm, with a mean score of 7.96 ± 0.88 compared with 7.61 ± 0.96 in the freehand arm ($p = 0.0155$).

No Schneiderian membrane perforations were observed in either study arm. All implants remained within safe anatomical boundaries, and no intraoperative or early postoperative complications were recorded.

V. CONCLUSIONS

Based on the presented studies, we draw the following conclusions, which we consider as the new scientific findings of the thesis:

1.Dynamic navigation can be successfully combined with osseodensification for transcrestal sinus augmentation and immediate implant placement. The case study demonstrated that this integrated workflow is technically feasible, enables controlled transcrestal membrane elevation, and preserves the integrity of the Schneiderian membrane while achieving adequate primary stability.

2. Trace-and-place registration provides a reliable and radiation-free method for dynamic navigation in posterior maxillary implant surgery. Its clinical application in the case study confirmed accurate intraoperative tracking without the need for fiducial markers or additional CBCT scans, thereby simplifying workflow and reducing patient exposure.

3. Dynamic navigation significantly improves the accuracy of implant placement compared with freehand surgery in indirect sinus lift procedures. In the randomized split-mouth trial, dynamically guided implants exhibited substantially lower entry, apex, and angular deviations, indicating that navigation enhances the fidelity of transferring the preoperative plan to the surgical field.

4. The use of osseodensification in both study arms establishes that improvements in spatial accuracy are attributable to navigation rather than mechanical

preparation of the osteotomy. The consistent primary stability across arms confirms that densification provides a uniform biomechanical baseline, isolating navigational guidance as the determinant of positional precision.

5. Dynamic navigation supports safe transcrestal sinus augmentation when residual bone height is limited. Across both studies, no Schneiderian membrane perforations were observed, suggesting that real-time trajectory control contributes to procedural safety in anatomically constrained regions.

6. Dynamic navigation does not compromise procedural efficiency or patient experience. Although calibration and registration require additional steps, total operative time remained comparable between navigated and freehand approaches, and patient satisfaction scores were high in both arms of the split-mouth trial.

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