Original Article

Stress Distribution around Dental Implants and Mandibular Bone Following Inferior Alveolar Nerve Lateralization and Implant Insertion: A Finite Element Analysis

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ABSTRACT

Background: Severe mandibular atrophy presents a challenge for dental implant placement, often necessitating inferior alveolar nerve lateralization (IANL).

Purpose: This study aimed to evaluate stress distribution in atrophic mandibles following IANL and dental implant insertion, comparing stress distribution across residual mandibular heights and implant configurations after simulated IANL using FEA method.

Materials and Method: Three-dimensional mandibular models derived from computed tomography (CT) scans were used to simulate implant placement after IANL in residual mandibular height models of 15 mm and 20 mm (20 mm included as a comparative reference). Stress distribution was analyzed under a static 100 N vertical (axial) occlusal load with the inferior mandibular border fixed, comparing splinted versus non-splinted prosthetic designs (three-implant splinted configuration versus two-implant bridge-supported configuration) and monocortical versus bicortical implant engagement.

Results: At a mandibular height of 20mm, stress distribution was consistent across configurations. However, at 15mm, stress concentrated along the crestal ridge, mental foramen, and osteotomy margins, exhibiting a broader distribution. A bridge-supported prosthesis demonstrated more favorable stress distribution than three individually fixed implants in the 15mm height models. Bicortical insertion did not significantly alter stress patterns.

Conclusion: IANL facilitates implant placement in severely atrophic mandibles. Implant configuration selection may influence stress concentration in reduced mandibular height models; in the 15 mm models, the bridge-supported configuration showed more favorable stress distribution than the three-implant configuration.

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Introduction

Tooth loss triggers a progressive alveolar ridge resorption process that substantially diminishes bone volume, presenting significant challenges for dental implant placement, particularly in cases of severe mandibular atrophy [1]. The posterior mandible is especially affected due to its limited bone height and density, which necessitates specialized surgical interventions for successful dental rehabilitation [2]. Traditional treatment approaches, such as bone grafting and guided bone regeneration, have long been employed, but they often involve extended healing periods and pose risks, such as donor site morbidity and unpredictable bone resorption [3]. Consequently, alternative techniques, including inferior alveolar nerve lateralization (IANL) and the use of short implants, have gained attention as viable solutions for implant placement in cases of severe mandibular atrophy [1]. However, concerns regarding the short implants and its effect on bone resorption have been raised. Recent biomechanical analyses suggest that higher crown-to-implant ratio values do not necessarily correlate with increased bone resorption, provided that the implant achieves stable osseointegration and optimal load distribution [4].

IANL is a surgical technique that temporarily repositions the inferior alveolar nerve (IAN), thereby creating additional space for implant insertion. This approach enables the placement of standard-length implants in anatomically challenging regions with insufficient bone height [5]. This method eliminates the need for bone grafting, reducing overall treatment time and costs while allowing for immediate implant placement [6]. Nevertheless, IANL is accompanied by inherent neurological risks, primarily manifesting as sensory disturbances including paresthesia, dysesthesia, and potential permanent anesthesia [5]. Research suggests that these nerve function alterations significantly affect patient comfort and quality of life, emphasizing the need for improved surgical protocols to minimize such risks [7].

To enhance the safety and effectiveness of IANL, piezoelectric surgical techniques have been introduced to reduce excessive bone loss and potential nerve injury [6]. Regenerative approaches, including autologous growth factors and enriched graft matrices, have also been proposed to improve neurosensory recovery [7]. Alongside these clinical advances, finite element analysis (FEA) is used increasingly to evaluate stress distribution in the mandible after IANL and implant placement under functional loading [2], providing biomechanical information that is difficult to obtain from clinical studies alone [8]. Nevertheless, removal of buccal cortical bone during IANL may weaken mandibular structure and increase fracture susceptibility [9], motivating investigation of supportive strategies such as patient-specific mandibular implants in severely atrophic ridges [10]. Previous finite element studies have evaluated stress behavior in atrophic posterior mandibles and implant-related load transfer under different configurations [12, 15-17]; however, comparative stress distribution after simulated IANL across different residual mandibular heights remains insufficiently characterized. The comparative biomechanical effects of residual mandibular height and implant configuration after IANL, specifically a two-implant bridge-supported restoration versus a three-implant configuration, and monocortical versus bicortical engagement remain insufficiently characterized. Therefore, this FEA compares stress distribution in computed tomography (CT)-derived mandibular models with 15mm and 20mm mandibular height following simulated IANL and implant insertion. We hypothesized that reduced mandibular height would increase stress concentration at the crestal ridge and osteotomy margins, and that implant configuration and cortical engagement would modulate stress transfer to the peri-implant bone.

Materials and Method

This study aimed to comprehensively assess the extent and severity of stress distribution in the mandible following IANL and dental implant insertion using FEA, a widely accepted computational method for evaluating biomechanical behavior.

A CT scan of an edentulous human mandible was obtained with axial, coronal, and sagittal slices spaced 1 mm apart to ensure detailed structural representation (Figure 1). Demographic characteristics (e.g., age and sex) of the scanned mandible were not reported in the manuscript.

The mandibular cortical and cancellous bone structures were segmented and reconstructed into 3D models using MIMICS (Materialize NV, version 21) and 3-MATIC software [11]. (Figure 2a) Natural teeth and prosthetic bridge designs were modeled using the same software.

Dental implant models were designed in monocortical and bicortical configurations using SOLIDWORKS (Dassault Systems, version 2019) (Figure 2b).

The implant models were initially exported in STL format, converted to STP format using the GEOMAGIC software, and subsequently imported into ANSYS (version 19.2, Canonsburg, PA, USA) for finite element simulation and stress analysis (Figure 3a-b).

The experimental setup included three factors: (1) residual mandibular height (15 mm vs 20 mm), (2) pros-

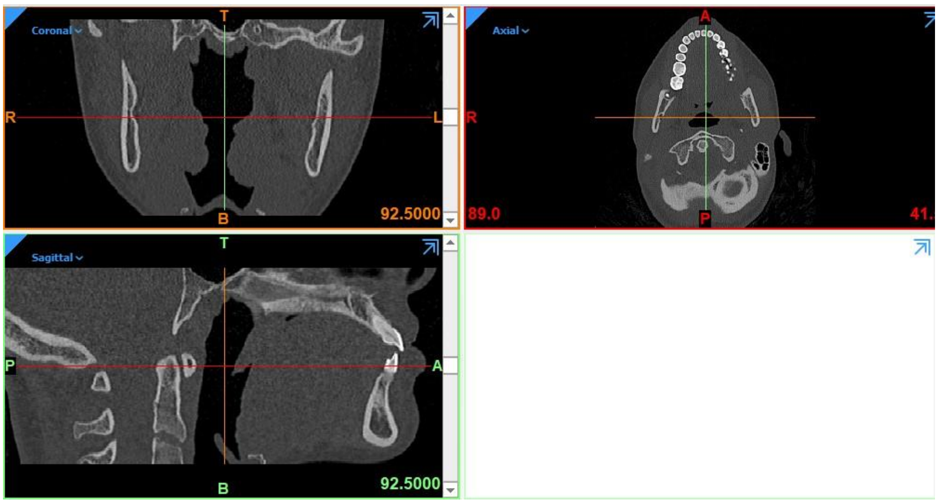

Figure 1: Axial, coronal, and sagittal CT views of an intact human mandible captured with a 1 mm interslice thickness, representing the first step in the imaging process

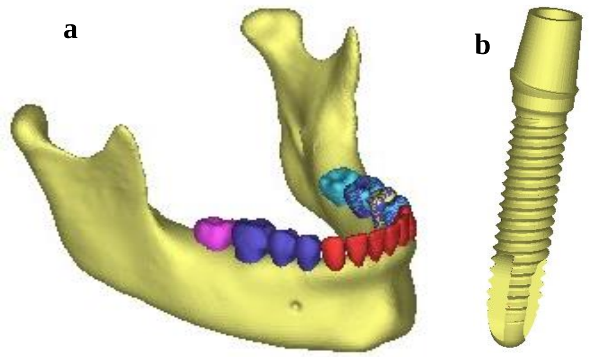

Figure 2: a: Constructed model of human mandible, extracted from CT images, **b:** Model of dental implant designed in SOLIDWORKS. Diameter of implants in this study is four mm

thetic design (two-implant bridge-supported configuration vs three-implant configuration), and (3) cortical engagement (monocortical vs bicortical). Models were generated by combining these factors to compare stress distribution across configurations (Table 1; Figure 4).

The assembled mandibular models were imported into the ANSYS software for FEA simulation. Material properties were adopted from published literature (Table 1) and were assumed to be homogeneous, isotropic, and linearly elastic. The total number of elements generated in the FEA model was 183,555 tetrahedral elements, while the total number of mesh nodes was 316,237 [8]. The implant–bone interface was defined as bonded contact to simulate complete osseointegration and to standardize stress transfer across models. Boundary conditions and loading were defined as follows (Figure 3a): the inferior border of the mandible was constrained as a fixed support. A static 100 N vertical (axial) occlusal load was applied to the second premolar crown area (Figure 3a). Buccal cortical bone removal was simulated to create the osteotomy window for IANL, enabling evaluation of stress concentration in the altered bone structure.

This study was approved by the Institutional Ethics Committee under the reference IR.MUMS.DENTISTRY.REC.1400.128. All the procedures adhered to ethical guidelines for biomechanical simulation in dental research.

Results

As shown in the finite element models (Figure 4) under the defined boundary condition and loading (Figure 3a), at a mandibular bone height of 20 mm, stress distribution patterns were similar regardless of prosthetic design. Additionally, stress severity patterns appeared similar between monocortical and bicortical implant insertions at this height based on qualitative assessment of the stress maps. In contrast, when the mandibular height was reduced to 15mm, a notable change in stress distribution was evident. In these cases, stress concentrations were primarily observed along the crestal ridge, the mental foramen, and the anterior edge of the osteotomy window. Furthermore, the stress extended over a broader area, encompassing the posterior part of the osteotomy window, symphysis region, and entire inferior border of the osteotomy window.

Discussion

FEA has proven to be an invaluable tool for evaluating the stress distribution following IANL and implant insertion in atrophic mandibles [11]. In the present study,

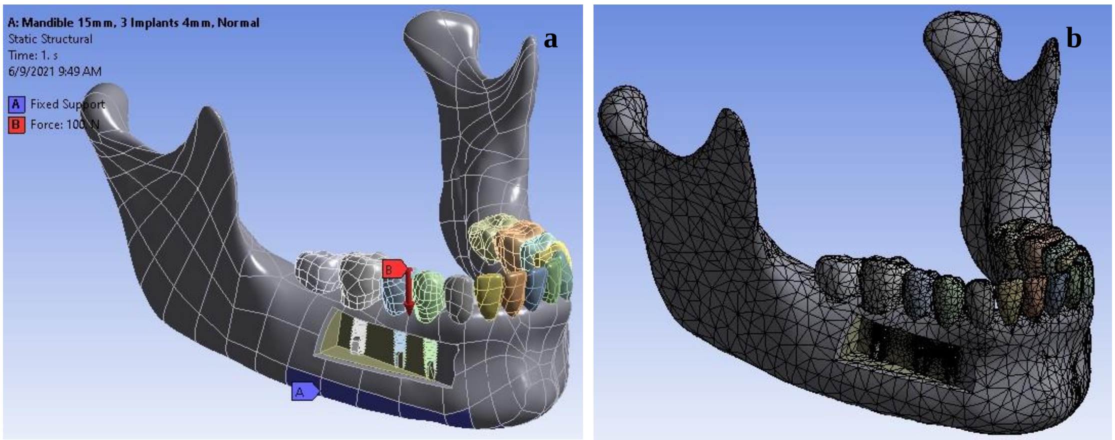

Figure 3: a: Boundary condition (fixed support at the inferior border of the mandible) and loading (a 100 N load applied to the second premolar area in the direction indicated in the figure); **b:** meshed model of the mandible

Table 1: Overview of experimental variations in implant number, bone height, and insertion type used to assess mandibular stress distribution

Material name	Modulus of elasticity (MP)	Poisson's ratio
Spongy bone	1,370	0.3
Teeth	22,000	0.3
Periodontal ligament	1,18	0.45
Cortical bone	13,700	0.3
Titanium implant	117,000	0.3

CT-based models were used to compare stress distribution across mandibular heights and implant configurations after simulated IANL. Our findings confirm that in cases of 15mm mandibular height, stress distribution is primarily concentrated around the crestal ridge, bone-implant contact points, the anterior border of the osteotomy window, and the mental, and the highest stress levels were observed at the bone-implant interface, reinforcing the importance of proper implant placement to minimize overload.

The impact of the IANL on mandibular integrity remains a concern, particularly in patients with severe atrophy. Intentional removal of the buccal bone to accommodate nerve lateralization weakens the mandible, a factor that must be carefully weighed against the benefits of implant placement. Recent research supports our findings that the dimensions of the osteotomy window play a crucial role in determining mandibular strength, with an increased risk observed in cases of lingually positioned inferior alveolar nerves [12]. Additionally, stress concentration around the mental foramen highlights the proximity of the osteotomy region to structures relevant to postoperative morbidity; clinical studies have evaluated outcomes and complications following IANL in atrophic mandibles [13]. However, the present FEA model does not assess longitudinal bone healing or neurosensory recovery. The classification of mandibular atrophy using the Luhr system remains relevant for surgical planning, particularly in guiding decisions on implant positioning and bone augmentation strategies [14]. In our study, the 15mm height classification aligns with Luhr's Class II atrophy, in which implant design and placement strategies are critical for maintaining biomechanical stability. In the 15mm models, a bridge-supported prosthesis demonstrated more favorable stress distribution than the three-implant configuration. These results align with previous finite element studies that have demonstrated that splinted prostheses distribute occlusal forces more evenly, reducing stress on individual implants and surrounding bone [15-17].

Our study also investigated whether the bicorticalization of implants offers advantages over monocortical placement. The results indicate that bicortical engagement does not provide significant biomechanical benefits in terms of fracture resistance, which supports prior research suggesting that preserving the integrity of the mandibular inferior border is critical for overall structural stability [3]. Additionally, while engaging the inferior portion of the mandible may enhance implant stability, excessive penetration of the inferior border should be avoided because of variations in bone volume and density [18].

A major finding of this study was the concentration of stress at the alveolar crest, which is consistent with prior finite element reports showing higher stress concentration in the crestal region under functional loading

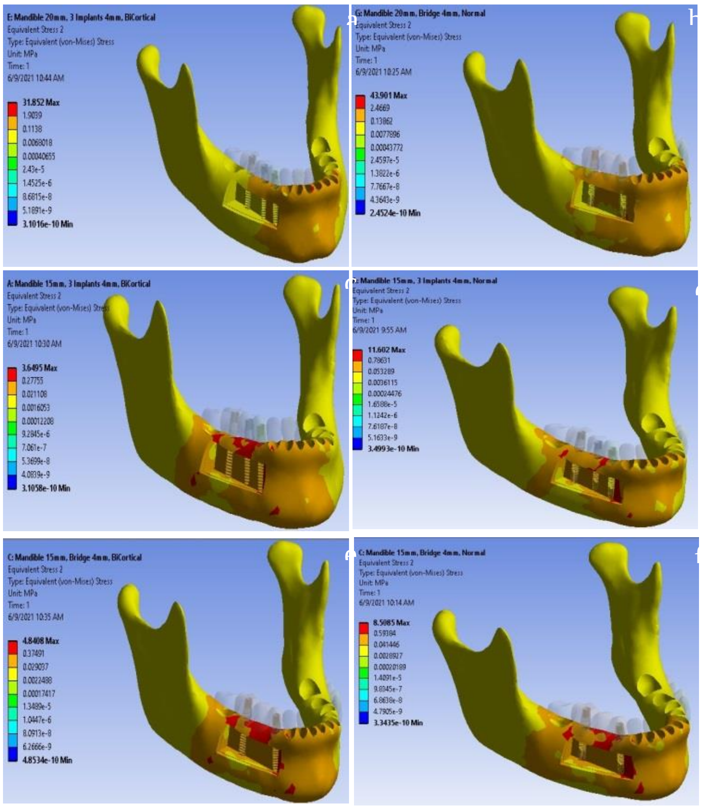

Figure 4: Finite element models illustrating variations in mandibular height (15 vs. 20mm), number of implants (2 vs. 3), and cortical insertion approach (monocortical vs. bicortical). The models were arranged from left to right as follows: (a) 20mm height, **a:** 20mm height, three implants, bicortical insertion, **b:** 20mm height, two implants, monocortical insertion, **c:** 15mm height, three implants, bicortical insertion, **d:** 15mm height, three implants, monocortical insertion, **e:** 15mm height, two implants, bicortical insertion, and **f:** 15mm height, two implants, monocortical insertion

[2, 6]. This observation aligns with the results of FEA performed by Fettahzade *et al.* [6], who highlighted that excessive stress accumulation in this region increases the risk of long-term implant failure. However, the clinical significance of stress concentration near the mental foramen cannot be determined from this simulation alone; clinical reports emphasize that postoperative outcomes depend on multiple surgical and patient-related factors beyond stress distribution patterns [9]. Given that neurosensory disturbance is a key complication of IANL, biomechanical findings should be inferred alongside the neurological outcomes reported in clinical studies. Although the present study evaluated stress distribution rather than nerve function, minimizing surgical trauma during IANL (e.g., atraumatic osteotomy techniques such as piezoelectric surgery) may be relevant to reducing postoperative neurosensory morbidity [19].

From a clinical planning perspective, the observed stress concentration patterns may help inform preoperative selection of implant configuration in software-assisted planning workflows, particularly in severely reduced mandibular height after IANL. Several limitations should be acknowledged. This study is based on a single CT-derived mandibular model, and demographic characteristics (e.g., age and sex) were not reported; therefore, anatomic variability and differences in bone quality were not captured. Loading was simulated as a static force under the specified boundary conditions (Figure 3a), which may not fully represent complex masticatory dynamics. In addition, the results depend on modeling assumptions (e.g., assigned material properties and implant–bone contact definition), and no external experimental or clinical validation was performed. Accordingly, the findings should be interpreted as comparative stress-distribution trends across configurations rather than definitive predictors of clinical outcomes.

Future studies should validate these stress-distribution trends against experimental or clinical data and evaluate long-term neurosensory outcomes and peri-implant bone changes following IANL.

Conclusion

IANL facilitates implant placement in severely atrophic mandibles. Implant configuration selection may influence stress concentration in reduced mandibular height models; in the 15mm models, the bridge-supported configuration showed more favorable stress distribution than the three-implant configuration.

Acknowledgment

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Conflicts of Interest

The authors declare that they have no conflict of interest.

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