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Stress Distribution in Basal and Crestal Alveolar Bone in Maxillary Rehabilitation Using Basal Implants - A Three-Dimensional Finite Element Analysis Study

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Abstract

Background: Severe maxillary alveolar resorption presents a major challenge for implant-supported rehabilitation because inadequate Crestal bone may limit conventional implant placement and necessitate augmentation procedures. Basal implants engage deeper, relatively dense cortical bone and permit immediate functional rehabilitation; however, their biomechanical stress distribution within the Crestal alveolar and basal bone requires further evaluation.

Aim: To evaluate the stress distribution in Crestal alveolar and basal bone surrounding basal implants used for rehabilitation of an atrophic edentulous maxilla under different loading conditions using three-dimensional finite element analysis.

Materials and Methods: A three-dimensional model of an atrophic edentulous maxilla was developed from computed tomography data. Ten basal implants were positioned in the reconstructed model and connected using an acrylic prosthetic framework. CT data were processed using MIMICS software and converted into an STL model for further processing. Material properties were assigned to bone and implant components based on published biomechanical data. Loads of 50, 150, 300 and

600 N were applied at 30° and 90° to simulate different functional loading conditions. Directional deformation and Von Misses stress distribution were evaluated in the Crestal alveolar bone and basal bone.

Results: Stress and deformation increased progressively with increasing load magnitude. At lower and intermediate loads, greater stress concentration was observed predominantly in the Crestal alveolar bone, particularly around the cervical implant region. At 150 N, the Crestal alveolar bone demonstrated greater stress than the basal bone. With increasing loading to 300 N and 600 N, stress transmission toward the basal bone progressively increased. The 30° loading condition demonstrated greater lateral deformation, whereas 90° loading produced predominantly axial force transmission.

Conclusion: Basal implants demonstrated load-dependent stress transfer between Crestal alveolar and basal bone. Increasing participation of the basal bone at higher loads supports its potential biomechanical importance in rehabilitation of severely atrophic maxillae.

Keywords: Basal Implants, Atrophic Maxilla, Crestal Alveolar Bone, Basal Bone, Stress Distribution, Finite Element Analysis, Von Mises Stress, Immediate Loading, Dental Implants, Maxillary Rehabilitation.

Introduction

Implant-supported rehabilitation has become an established treatment option for edentulous patients, however, rehabilitation of the severely atrophic maxilla remains a significant clinical and biomechanical challenge[1]. Progressive resorption of the alveolar ridge results in reduced bone height and width and may be accompanied by poor bone quality, particularly in the posterior maxilla. These factors can compromise primary implant stability and alter the pattern of stress transmission from the implant to the surrounding bone. A finite element analysis of implants placed in normal and atrophic edentulous maxillae demonstrated that bone quantity and quality substantially influence peri-implant stress and strain, with the combination of atrophic dimensions and poor bone quality capable of producing supra physiological bone strains under mechanical loading[2].

Conventional end osseous implants primarily depend on adequate crestal alveolar bone for primary stability and osseointegration. In severely resorbed maxillae, insufficient residual bone may therefore necessitate additional procedures such as bone augmentation or sinus floor elevation before implant placement. These procedures may increase treatment complexity, surgical morbidity, cost and treatment duration. Basal Implantology has emerged as an alternative approach for selected patients with severe jaw atrophy. Basal implants are designed to obtain anchorage from deeper, more cortical regions of the jaw rather than relying predominantly on the resorbed Crestal alveolar ridge. Their structural characteristics and cortical anchorage have facilitated immediate-loading approaches and rehabilitation in situations in which conventional implant therapy may be difficult[3,4].

Clinical evidence has demonstrated the feasibility of basal implant-supported rehabilitation in severely resorbed jaws. Patel et al., in a prospective study evaluating basal implants in atrophied and resorbed maxillary and mandibular jaws, reported favourable clinical outcomes and highlighted the potential of basal implants as an alternative treatment modality in patients with inadequate alveolar bone[3]. Similarly, Ghalaut et al. reported successful full-mouth rehabilitation using immediately loaded single - piece basal implants, demonstrating the clinical applicability of this approach in patients with compromised alveolar bone[4]. Longer-term clinical observations have also reported favourable implant survival and peri-implant tissue outcomes following immediately loaded basal implant-supported rehabilitation in selected patients[5]. These clinical findings provide support for the use of basal implants; however, clinical survival alone does not adequately explain the underlying biomechanical mechanisms responsible for load transfer.

The distribution of mechanical stresses between an implant and its supporting bone is an important determinant of implant stability and peri-implant bone response. The magnitude and location of stress are influenced by implant geometry, bone quality and quantity, implant position, prosthetic design, loading direction and magnitude, and the nature of the bone–implant interface. In atrophic maxillae, the reduced quantity of Crestal bone may substantially modify these stress-transfer patterns. Meyer et al. demonstrated using finite element analysis that atrophic maxillary bone, particularly when associated with poor bone quality, may experience increased peri-implant strains under loading[2]. These findings emphasize the importance of understanding how implant-supported forces are transmitted through different regions of the remaining maxillary bone.

Finite element analysis (FEA) is a well-established computational method for investigating biomechanical behaviour in complex implant–bone systems. It permits visualization and quantification of stress and deformation under controlled loading conditions and can therefore be used to compare different implant configurations and bone-support conditions. Freedman et al. developed a three-dimensional finite element model to investigate the effect of maxillary alveolar bone support on zygomatic implants. Their analysis showed higher maximum stresses when alveolar support was removed, demonstrating that residual maxillary alveolar bone can contribute substantially to force distribution even when implants obtain major anchorage from deeper skeletal structures[6]. A subsequent finite element study of zygomatic implants placed in an extra-sinus position similarly demonstrated that removal of maxillary alveolar support increased maximum stress, further emphasizing the biomechanical contribution of residual alveolar bone[7].

Finite element modeling has also been specifically applied to basal implants. Ihde et al. developed a finite element model to investigate the bone–implant interface of basal implants during different stages of healing. Their findings demonstrated that changes in the bone–implant contact condition altered both the magnitude and location of peak Von Mises stresses, indicating that the mechanical behaviour of basal implants is influenced by the nature of their interaction with the surrounding bone[8]. The authors emphasized the importance of incorporating changes in bone–implant contact when interpreting finite element models of basal implant systems.

Although previous finite element investigations have examined implant loading in atrophic maxillae and the contribution of residual alveolar bone to the biomechanics of zygomatic and other skeletal implants, comparatively limited information is available regarding the relative stress distribution between Crestal alveolar bone and deeper basal bone surrounding multiple basal implants in an atrophic edentulous maxilla. In particular, the effect of different loading magnitudes and loading directions on the transition of stress from the Crestal alveolar region to the basal bone remains inadequately characterized.

Understanding this biomechanical relationship is clinically relevant because basal implant therapy is specifically intended to obtain support from deeper cortical bone in situations where conventional Crestal anchorage is compromised. Identification of the regions that experience greater stress under different functional loading conditions may contribute to improved implant positioning, prosthetic design and treatment planning. It may also provide a biomechanical basis for determining favourable implant locations in severely atrophic maxillae.

Therefore, the present three-dimensional finite element analysis was undertaken to evaluate the distribution of stress and deformation in the Crestal alveolar and basal bone surrounding ten basal implants placed in an atrophic edentulous maxilla. Different loading magnitudes and loading directions were applied, and Von Mises stress distribution was assessed to determine the relative contribution of the Crestal alveolar and basal bone to load transfer.

The findings are intended to improve understanding of the biomechanical behaviour of basal implants and provide a basis for optimizing implant placement and maxillary rehabilitation in patients with severe alveolar atrophy.

Aim and Objectives

Aim

To evaluate the distribution of stress in the Crestal alveolar and basal bone surrounding basal implants during maxillary rehabilitation under different loading conditions using three-dimensional finite element analysis.

Objectives

1. To determine the influence of residual maxillary alveolar bone support on the biomechanical stability of basal implants in an edentulous atrophic maxilla.
2. To compare stress distribution between the Crestal alveolar bone and basal bone under axial and lateral loading conditions.
3. To evaluate the effect of different loading magnitudes and loading angles on stress distribution around basal implants.
4. To identify the bone region that demonstrates greater stress-bearing capacity under increasing occlusal loads.

Materials and Methods

Study Design

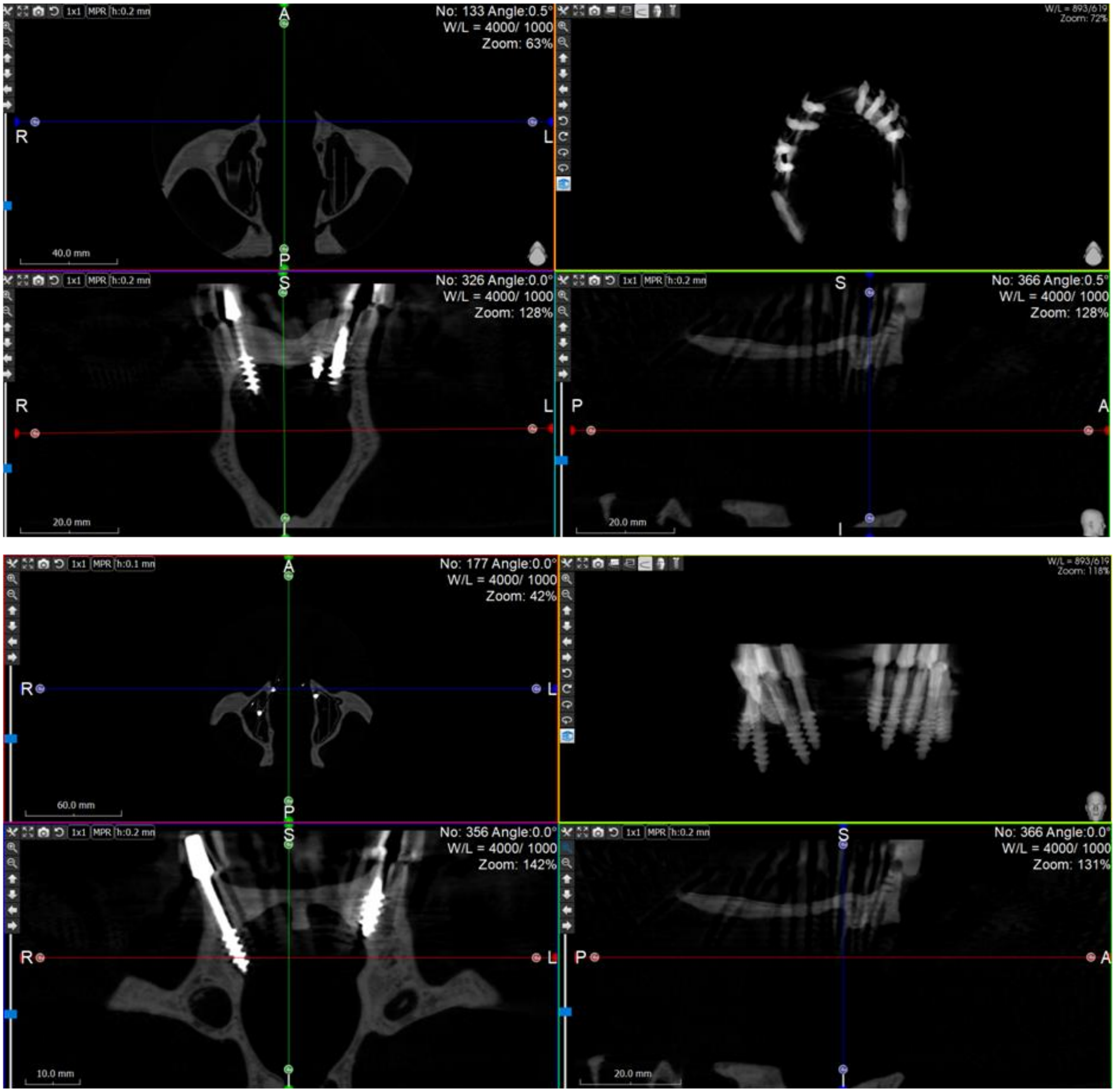
The present investigation was conducted as a three-dimensional finite element analysis (FEA) study to evaluate the distribution of stress in the Crestal alveolar and basal bone surrounding basal implants used for rehabilitation of an atrophic edentulous maxilla. The analysis was designed to assess the biomechanical response of the implant–bone–prosthesis complex under different magnitudes and directions of functional loading.

Study Model

A three-dimensional model of an atrophic edentulous adult maxilla was used as the anatomical basis for the study. Computed tomography (CT) imaging was used to reproduce the anatomical morphology of the maxilla and to facilitate reconstruction of the bony structures in a computer-aided environment.

The CT dataset was used to generate a three-dimensional representation of the residual maxillary bone. Particular attention was given to the residual Crestal alveolar bone and the deeper basal bone, as these regions were considered the principal areas contributing to implant support in the atrophic maxilla.

Chart 1:



Armamentarium and Study Materials

The materials and equipment used for construction of the experimental model included:

1. CT dataset of an atrophic edentulous maxilla.
2. Three-dimensional STL model of the maxilla.
3. Basal implants.
4. Contra-angled handpiece for implant placement.
5. Impression material.
6. Impression sleeves and implant analogues.
7. Acrylic prosthetic framework.

8. Computer-aided three-dimensional modelling and finite element analysis software.

Acquisition and Reconstruction of the Maxillary Model

CT imaging of an atrophic edentulous adult maxilla was used to obtain sequential axial images of the maxillofacial region. The CT data were imported into MIMICS software for image processing and three-dimensional reconstruction.

The CT slices were examined and segmented using appropriate threshold values corresponding to the radiodensity of bone. The region of interest was isolated from the surrounding structures, and the segmented images were reconstructed to obtain a three-dimensional representation of the atrophic maxilla.

The reconstructed anatomical model was subsequently converted into a three - dimensional surface representation and exported in Standard Tessellation Language (STL) format. The STL file provided the basis for further modification and preparation of the finite element model.

Editing and Preparation of the Three-Dimensional Model

The STL model obtained from MIMICS was imported into **Netfabb** software for correction and editing of the three-dimensional surface. Errors such as discontinuities, unwanted surface irregularities, and geometric defects were corrected wherever required.

The processed STL model was then transferred to Rhinoceros software for further three-dimensional modeling and preparation of the implant–bone–prosthesis assembly. The geometry of the model was optimized to facilitate subsequent finite element meshing and analysis.

Basal Implant Placement

A total of 10 basal implants were placed in the three-dimensional model of the atrophic edentulous maxilla. Implant positioning was planned to reproduce a clinically relevant full-arch basal implant-supported rehabilitation. The implants were positioned using a contra-angled hand piece according to the anatomical morphology of the reconstructed maxilla. The implant positions were selected to obtain support from the available residual bone while extending anchorage toward the deeper basal bone.

The implant–bone relationship was incorporated into the three-dimensional model for subsequent biomechanical analysis. The implant configuration was maintained consistently across the loading conditions to allow comparison of stress distribution under different applied forces.

Impression and Prosthetic Framework Fabrication

Following placement of the 10 basal implants, an impression of the implant-supported model was obtained using impression material and appropriate impression sleeves. Implant analogues were incorporated into the impression to reproduce the implant positions accurately.

An acrylic prosthetic framework was subsequently fabricated according to the reconstructed implant positions. The framework was adapted to the implant abutments and connected to the basal implants to simulate a full-arch implant-supported prosthesis.

The completed implant–framework assembly was used to reproduce the prosthetic component in the finite element model.

CT Acquisition of the Implant-Supported Model

After placement of the implants and fabrication of the acrylic framework, the reconstructed model was subjected to CT imaging. The resulting CT dataset was used to obtain the spatial relationship between the maxillary bone, basal implants, and prosthetic framework.

The CT images were subsequently imported into the modelling environment and processed to reproduce the experimental configuration digitally. This approach allowed the geometry of the bone, implants, and prosthetic framework to be incorporated into a three-dimensional computational model.

Finite Element Model Development

The three-dimensional anatomical and prosthetic models were converted into a computational model suitable for finite element analysis. The model consisted principally of

- Crestal alveolar bone
- Basal bone
- Basal implants
- Acrylic prosthetic framework

The interfaces between the different components were defined according to their anatomical and mechanical relationships. The resulting geometry was discretized into finite elements to permit numerical calculation of deformation and stress under applied loads.

The finite element model was subsequently used to investigate the mechanical response of the implant-supported maxilla under different loading conditions.

Material Properties

The mechanical properties assigned to the different components of the model were based on values reported in previously published experimental and biomechanical literature.

The properties assigned to the bone model were derived from averaged values obtained from cadaveric studies of craniofacial and skull bone. The implant and prosthetic framework were modeled according to the mechanical characteristics of commercially pure titanium, as applicable to the implant components used in the study.

The same material properties were maintained across the different loading simulations to permit direct comparison of the resulting stress and deformation patterns.

Loading Conditions

To investigate the biomechanical behaviour of the implant-supported maxilla under different functional conditions, external loads were applied to the prosthetic framework at different magnitudes and directions.

Four magnitudes of force were evaluated:

- 50 N
- 150 N
- 300 N
- 600 N

The forces were applied under two principal loading configurations:

1. 30° loading condition
2. 90° loading condition

The loading conditions were designed to represent different combinations of axial and lateral components of functional occlusal loading. The 30° configuration introduced an oblique component of loading, whereas the 90° configuration represented a predominantly axial loading condition.

Each loading magnitude was separately applied to the model while maintaining the same implant configuration and material properties.

Deformation Analysis

The deformation of the implant–bone–prosthesis complex was evaluated following application of each simulated load. Directional deformation was assessed at 30° and 90° loading conditions for 50 N, 150 N, 300 N, and 600 N.

The deformation pattern was examined to identify regions demonstrating greater displacement in response to increasing applied force. The results were visually represented using the corresponding finite element deformation maps.

Stress Analysis

The principal outcome of the study was the distribution of stress within the bone surrounding the basal implants.

The stress generated within the model was assessed using **Von** Mises stress analysis. Von Mises stress provides an equivalent stress value that allows comparison of the magnitude and distribution of mechanical stress within the model.

Stress distribution was evaluated separately in:

1. Crestal alveolar bone
2. Basal bone

The stress patterns were examined under each combination of loading magnitude and loading angle. Particular attention was paid to areas of stress concentration around the implant–bone interface and within the supporting bone.

Comparison of Crestal Alveolar and Basal Bone Stress

The stress distribution obtained from the finite element simulations was compared between the crestal alveolar and basal bone regions.

At each loading magnitude, the relative stress concentration in the two regions was evaluated. The purpose of this comparison was to determine whether the Crestal alveolar bone or deeper basal bone represented the predominant stress-bearing region under different functional loading conditions.

The results were also examined to determine whether increasing occlusal force altered the relative contribution of the two bone regions to overall load transfer.

Data Analysis and Interpretation

The finite element analysis generated numerical and colour-coded graphical representations of stress and deformation. The resulting stress maps were examined according to the magnitude and location of Von Mises stress.

The following comparisons were performed

- Stress distribution at 30° versus 90° loading.
- Stress distribution at 50 N, 150 N, 300 N, and 600 N.
- Stress distribution in crestal alveolar bone versus basal bone.
- Changes in stress concentration with increasing applied load.
- Directional deformation under different loading conditions.

The areas demonstrating relatively greater stress concentration were identified from the finite element output and interpreted in relation to the anatomical location of the Crestal alveolar and basal bone.

Outcome Measures

The primary outcome measure was:

Distribution of Von Mises stress in the crestal alveolar and basal bone surrounding the basal implants under different loading conditions.

Secondary outcome measures included

1. Directional deformation of the implant–bone–prosthesis complex.
2. Effect of loading angle on stress distribution.
3. Effect of increasing load magnitude on stress distribution.
4. Relative contribution of crestal alveolar and basal bone to stress bearing.

5. Identification of regions demonstrating increased stress concentration around the implant-supported reconstruction.

Reproducibility of the Finite Element Analysis

To facilitate comparison between loading conditions, the same three-dimensional anatomical model, implant configuration, material properties, and prosthetic framework were maintained throughout the analysis. Only the magnitude and direction of the applied load were varied between simulations.

This standardized approach enabled evaluation of the independent effect of loading conditions on stress distribution within the Crestal alveolar and basal bone.

Ethical Considerations

As the study was based on a previously acquired CT dataset and involved a computer-based finite element model rather than intervention on human participants, no additional clinical intervention was performed for the purpose of the biomechanical analysis. If the CT dataset was obtained from a human subject specifically for the study, the appropriate institutional ethics committee approval and informed consent should be reported in accordance with the actual study protocol.

Statistical Considerations

Finite element analysis was primarily used as a computational biomechanical modeling technique. Stress and deformation values generated under the predefined loading conditions were compared descriptively across the different loading angles, force magnitudes, and anatomical regions. Since the study involved a single computational model rather than independent biological samples, conventional inferential statistical tests were not considered appropriate unless repeated model simulations or sensitivity analyses were incorporated into the study design.

Results

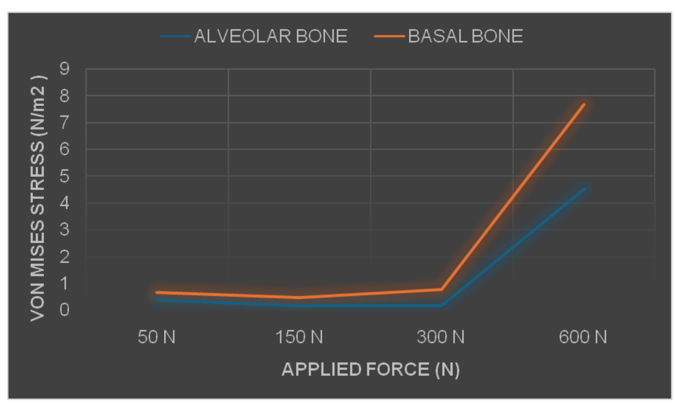
Overall stress distribution

The three-dimensional finite element analysis demonstrated a distinct pattern of stress distribution within the implant–bone complex under different loading conditions. Stress was evaluated in the Crestal alveolar bone and basal bone surrounding the ten basal implants. The model was subjected to loads of 50 N, 150 N, 300 N and 600 N at loading angles of 30° and 90°. The distribution of stress was assessed using the Von Mises stress criterion, while directional deformation was evaluated to determine the mechanical response of the implant-supported maxillary rehabilitation.

Overall, the magnitude of stress and deformation increased progressively with increasing applied load. The distribution was not uniform throughout the maxillary bone. Greater stress concentration was observed around the implant-bearing regions, particularly at the Crestal alveolar bone under lower and intermediate loading conditions. With increasing loading magnitude, stress was increasingly transferred to the deeper basal bone.

Stress distribution at 30° loading

Figure 1: Stress Distribution At 30 Degrees.



At a loading angle of **30°**, the finite element model demonstrated a greater concentration of stress in the Crestal alveolar region under lateral loading compared with axial loading. The stress pattern was predominantly localized around the implant–bone interface and the Crestal portion of the supporting bone.

At 50 N, the deformation and stress concentration were relatively low and were mainly restricted to the immediate peri-implant region. The surrounding basal bone showed comparatively lower stress concentration.

With an increase in loading to 150 N, there was a noticeable increase in stress concentration within the crestal alveolar bone. The maximum stress was predominantly concentrated around the cervical/crestal region of the implants, indicating that the residual alveolar bone continued to contribute substantially to load transfer at this stage.

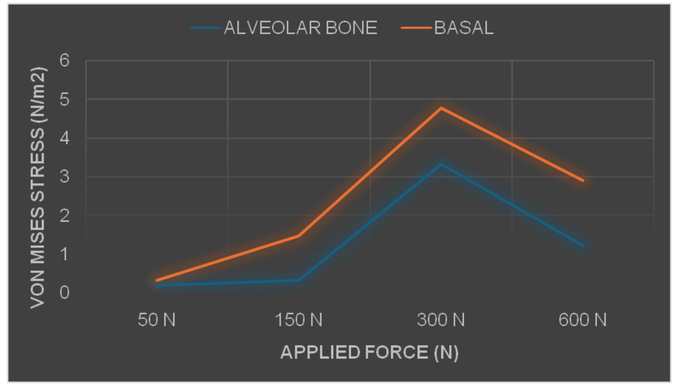
At 300 N, a further increase in stress was observed in the alveolar bone. The stress distribution became more extensive around the implant-bearing region, indicating greater transmission of functional forces through the Crestal portion of the maxilla. The increase was particularly evident when the model was subjected to lateral loading.

At 600 N, the overall magnitude of stress and deformation increased considerably. However, the pattern of load transfer differed from that observed at lower loading levels. A greater proportion of the applied force was transmitted toward the deeper basal bone, with the basal region demonstrating increased stress participation compared with the lower-load conditions.

Thus, at 30° loading, the model demonstrated a progressive increase in stress with increasing load, with Crestal alveolar bone predominating as the stress-bearing region at lower and intermediate loads and greater involvement of basal bone at higher loads.

Stress distribution at 90° loading

Figure 2: Stress Distribution At 90 Degree



At 90° loading, representing a predominantly axial loading condition, the stress distribution was comparatively more aligned with the long axis of the implants. The stresses were transmitted through the implant bodies toward the supporting bone with relatively less lateral displacement than observed at 30° loading.

At 50 N, only limited stress concentration was observed around the implant–bone interface. The stress was relatively localized, with minimal deformation of the surrounding bone.

At 150 N, stress concentration increased, with the Crestal alveolar bone demonstrating greater stress than the basal bone. The region adjacent to the cervical portion of the implants showed the most prominent stress concentration. This indicates that the residual Crestal bone contributed significantly to initial load transfer under axial loading.

At 300 N, a substantial increase in stress was observed within the alveolar bone. The stress distribution extended from the Crestal region toward the deeper supporting bone, suggesting progressive transmission of the applied axial force through the implant–bone complex.

At 600 N, the overall stress magnitude and deformation were highest. At this higher load, increased stress transmission into the basal bone was evident. The basal bone consequently demonstrated a greater contribution to overall load-bearing compared with the lower loading conditions.

The 90° loading configuration therefore demonstrated a predominantly axial transfer of force through the implants, with initial stress concentration in the Crestal alveolar bone followed by increasing stress transmission toward the basal bone as the applied load increased.

Directional deformation

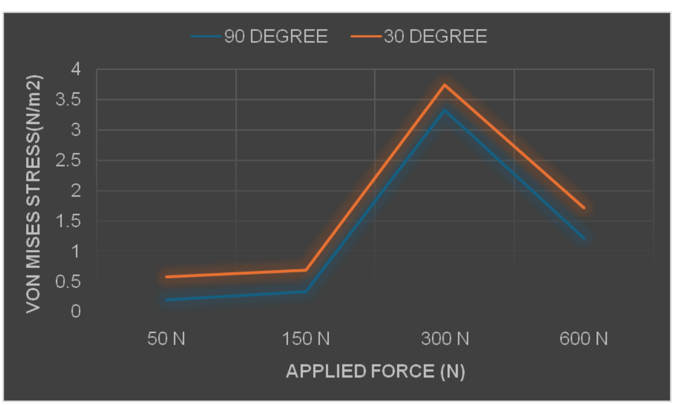
Directional deformation showed a progressive increase with increasing magnitude of applied load. The lowest deformation was observed at 50 N, whereas the greatest deformation occurred at 600 N.

At both 30° and 90° loading conditions, the pattern of deformation was directly related to the magnitude and direction of the applied force. The 30° loading configuration produced a greater lateral component of deformation because of the oblique nature of the applied force. In contrast, deformation under 90° loading was predominantly directed along the axis of loading.

The deformation pattern remained concentrated around the implant-supported framework and the surrounding bone. No abrupt discontinuity in the model was observed during the simulated loading conditions.

Comparison between Crestal alveolar and basal bone

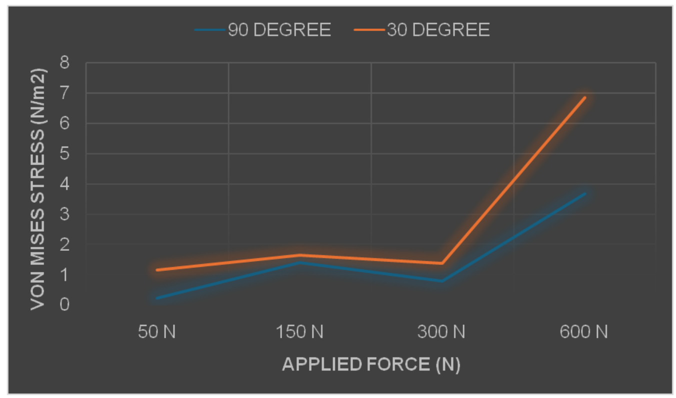
Figure 3: Stress Distribution At Alveolar Bone



Comparison of the two major supporting regions demonstrated a load-dependent difference in stress distribution. At lower loading levels, particularly 50 N and 150 N, the Crestal alveolar bone demonstrated relatively greater stress concentration than the basal bone. This was most evident around the cervical region of the implants.

At 300 N, a marked increase in stress was observed in the alveolar bone. This represented a transition phase in the distribution of functional forces, with increasing transmission of stress toward the deeper basal region.

Figure 4: Stress Distribution At Basal Bone



At 600 N, the basal bone demonstrated a greater relative contribution to stress distribution. The deeper cortical region appeared to accommodate an increasing proportion of the applied load, while the relative dominance of the Crestal alveolar bone in stress transmission was reduced.

The observed pattern indicates that the two bone regions do not contribute equally under all loading conditions. Instead, stress transfer appears to be dependent on the magnitude and direction of the applied force, with the crestal alveolar bone being more involved at lower loads and the basal bone becoming increasingly involved as the loading magnitude increases.

Overall FEA finding

The finite element model demonstrated that basal implants were capable of transferring functional loads from the prosthetic framework to both the Crestal alveolar and deeper basal components of the atrophic maxilla. The distribution of stress was influenced by the loading angle, magnitude of applied force and location of supporting bone.

The principal observation was that the Crestal alveolar bone experienced relatively greater stress at lower and moderate loading conditions, whereas increasing the applied load resulted in progressively greater stress transmission to the basal bone. This load-dependent shift was more evident at higher loading magnitudes.

The findings suggest that the deeper basal bone may act as an important secondary load-bearing region in severely atrophic maxillae rehabilitated with basal implants. The engagement of the basal bone may allow functional forces to be distributed beyond the compromised Crestal alveolar region.

Table 1: Distribution of stress according to loading magnitude and loading angle

Loading angle	Load	Crestal alveolar bone	Basal bone	Overall deformation
30°	50 N	Low stress concentration	Minimal stress	Minimal
30°	150 N	Increased stress concentration	Relatively lower	Mild
30°	300 N	Marked increase in stress	Increasing stress participation	Moderate
30°	600 N	High stress with greater basal load transfer	Increased contribution	Maximum
90°	50 N	Low stress concentration	Minimal stress	Minimal
90°	150 N	Predominant stress concentration	Relatively lower	Mild
90°	300 N	Marked increase in stress	Increasing stress participation	Moderate
90°	600 N	High stress with increased basal transmission	Greater load-bearing contribution	Maximum

The most important finding of the present analysis was the progressive shift in load transfer from the Crestal alveolar bone toward the basal bone with increasing loading magnitude.

At lower loads, the Crestal alveolar bone represented the predominant region of stress concentration, whereas higher loads resulted in increasing participation of the basal bone. This finding supports the biomechanical rationale for utilizing basal implants in severely atrophic maxillae where the available Crestal alveolar bone is inadequate.

Discussion

The present three-dimensional finite element analysis was undertaken to evaluate the distribution of stress between the Crestal alveolar and basal bone in an atrophic edentulous maxilla rehabilitated with basal implants. The principal finding of the study was that stress distribution was dependent on both the magnitude and direction of loading. At lower and intermediate loading levels, particularly at 150 N, the Crestal alveolar bone demonstrated greater stress concentration than the basal bone. With increasing loading, particularly at 300 N and 600 N, stress transmission to the deeper basal bone progressively increased. This observation suggests that the basal bone contributes increasingly to load bearing as the functional load rises.

The biomechanical rationale for basal Implantology differs from that of conventional Crestal implants. Conventional implants primarily utilize the available alveolar process, which undergoes progressive resorption following tooth loss. Basal implants are designed to obtain anchorage from deeper cortical regions of the jaw, thereby providing an alternative means of stabilization in severely resorbed ridges. Patel et al., in a prospective clinical study of strategic basal implants used for rehabilitation of atrophied maxillary and mandibular jaws, highlighted the applicability of basal implants in situations where conventional implant placement is limited by inadequate residual alveolar bone[3]. Their findings support the clinical concept underlying the present FEA model, although the present study specifically investigates the biomechanical mechanism rather than clinical treatment outcomes.

An important observation in the present study was the relatively greater stress concentration in the Crestal alveolar bone at lower loading levels. This finding is consistent with the concept that the Crestal region continues to participate substantially in initial load transfer even when implants are designed to engage deeper basal bone. Freedman et al. evaluated the influence of maxillary alveolar bone support on zygomatic implants using three-dimensional FEA and found that removal of alveolar support resulted in higher maximum von Mises stresses. They concluded that preservation of maxillary alveolar support was beneficial for force distribution[6]. Although zygomatic implants differ considerably from basal implants in design and anchorage, the principle that residual alveolar bone contributes to the distribution of functional forces is relevant to the present findings.

The observation that stress increased progressively with increasing applied force is also consistent with previous finite element investigations. Freedman et al. reported that maximum stress increased approximately linearly as the applied force increased in their zygomatic implant models[6].

A similar load-dependent response was demonstrated in the present model, with progressive increases in stress and deformation from 50 N through 150 N, 300 N and 600 N. This finding is biomechanically expected because increasing the magnitude of the applied force increases the mechanical demand placed on the implant–bone–prosthesis complex. The clinical significance, however, depends not only on the absolute stress but also on its location and the mechanical properties of the involved bone.

The results at 150 N are particularly relevant. At this loading level, the Crestal alveolar bone demonstrated greater stress concentration compared with the basal bone. This suggests that the residual crestal bone may initially absorb and transmit a substantial component of functional loading before the deeper basal bone becomes increasingly involved. Such a pattern is important in severely atrophic maxillae because it indicates that basal implant placement should not necessarily be considered independent of the remaining alveolar bone. Even when the implant derives its principal anchorage from basal cortical structures, the residual Crestal bone may contribute to overall force distribution.

With increasing loading to 300 N and 600 N, the present model demonstrated increasing stress transmission toward the basal bone. This finding is consistent with the fundamental design principle of basal implants, in which deeper cortical bone is utilized for implant anchorage. Ihde et al. specifically investigated bone–implant contact with basal implants using FEA and demonstrated that the magnitude and location of peak von Mises stress changed according to the assumed bone–implant contact condition. Their model showed that stress patterns could shift at the implant–bone interface depending on the mechanical characteristics of the contact region[8]. The authors emphasized that finite element models evaluating basal implants should account for changes in bone–implant contact and biological adaptation over time.

The findings of Ihde et al. are particularly relevant to the present study because both investigations emphasize that stress distribution is not static. In the present model, changes were observed according to loading magnitude and direction, whereas Ihde et al. demonstrated changes associated with different bone–implant contact conditions representing stages of healing[8]. Thus, the stress-bearing behaviour of basal implants is likely to be influenced by multiple interacting variables, including implant geometry, cortical bone engagement, loading direction, loading magnitude and bone–implant contact.

The present study also demonstrated a difference between 30° and 90° loading conditions. At 30°, the oblique direction of loading introduced a lateral component, resulting in greater directional deformation and increased stress concentration in the Crestal region. In contrast, 90° loading produced predominantly axial transmission of force through the implant–bone complex. These findings emphasize the importance of loading direction in the biomechanical performance of implant-supported rehabilitation. The effect of force direction has also been demonstrated by Freedman et al. in their FEA studies of zygomatic implants. In their original 2013 study, occlusal and lateral forces produced different stress patterns, and the absence of alveolar support increased maximum stress[6]. In their subsequent 2015 study of extra-sinus zygomatic implants, they again demonstrated that stress distribution differed according to the direction of applied force and the presence or absence of maxillary alveolar support[7].

An important biomechanical implication of the present findings is the apparent progressive participation of basal bone with increasing load. At lower loading conditions, the Crestal alveolar region was the predominant area of stress concentration, whereas at higher loads the basal bone demonstrated increasing stress-bearing involvement[9]. This may be advantageous in severely atrophic maxillae because the deeper cortical structures can provide an additional load-bearing pathway when the available Crestal bone is limited. However, this interpretation should be considered cautiously because increased stress in basal bone does not necessarily imply improved implant survival. Rather, it indicates that the basal region is participating more substantially in force transmission.

The clinical literature provides some supportive evidence for the feasibility of immediate loading with basal implants. Ghalaut et al. reported a case of full-mouth rehabilitation using 18 single-piece basal implants with immediate functional loading and observed favourable clinical outcomes during follow-up[4]. They emphasized the importance of primary stability in dense cortical bone and rigid splinting for distributing functional forces among implants. Similarly, Awadal kreem et al. evaluated 97 basal cortical screw implants in 15 patients following marginal mandibulectomy and reported 100% implant survival and success during their reported follow-up, together with favourable peri-implant clinical and radiographic findings[5]. These clinical observations support the practical feasibility of immediate loading; however, they cannot be directly equated with the stress patterns observed in the present computational model.

The importance of splinting and prosthetic framework design is also relevant to the present model. In basal implant rehabilitation, multiple implants are commonly connected by a rigid prosthetic framework, which can facilitate redistribution of functional forces across the implant-supported reconstruction. Ghalaut et al. specifically described the use of a rigid framework to distribute masticatory forces among implants[4]. Therefore, the stress distribution observed in the present study should be interpreted as the response of a multi-implant splinted system, rather than the response of an isolated implant. This distinction is important because the biomechanical behaviour of a full-arch rehabilitation may differ considerably from that of a single implant.

The present findings have potential implications for implant positioning in severely atrophic maxillae. The observation that stress distribution changes between crestal and basal bone with increasing loading suggests that the location and extent of cortical engagement may influence the mechanical behaviour of the reconstruction. A strategic implant position that allows engagement of favourable basal cortical structures while maintaining appropriate prosthetic distribution may therefore contribute to more favourable load transfer. However, such conclusions should not be generalized directly to clinical practice without validation using patient-specific models and clinical outcome studies.

The present study also demonstrates the value of FEA in evaluating complex implant–bone interactions. CT-based three-dimensional reconstruction allows the anatomical morphology of an atrophic maxilla to be incorporated into the computational model. This approach was similarly used by Freedman et al., who developed a three-dimensional model from CT data to investigate stress distribution around zygomatic implants[6,7]. FEA therefore provides an opportunity to investigate loading patterns that would be difficult to measure directly in vivo.

Nevertheless, several limitations inherent to FEA should be considered when interpreting the present findings. The model represents a mathematical approximation of biological tissues. Bone was assigned material properties derived from published data, whereas actual maxillary bone demonstrates considerable heterogeneity in density, cortical thickness and elastic properties. Similarly, the bone–implant interface was modeled according to predefined assumptions and may not fully reproduce the complex biological interface present clinically. Ihde et al. demonstrated that different assumptions regarding bone–implant contact can substantially influence both the magnitude and location of calculated stresses[8].

Furthermore, the present analysis evaluates static loading conditions and does not reproduce the complex cyclic and multidirectional nature of mastication. Para functional loading, individual variations in occlusal force, progressive bone remodeling and long-term changes in bone–implant contact were not incorporated into the model. Therefore, the finding of increased basal bone stress at higher loads should be interpreted as a mechanical observation rather than direct evidence of enhanced long-term implant survival[10].

Taken together, the findings of the present study indicate that the Crestal alveolar and basal bone have complementary roles in the transmission of forces around basal implants. The Crestal alveolar bone appears to contribute substantially to load transfer at lower and moderate loading levels, whereas the basal bone becomes increasingly involved as loading increases[11]. The difference between 30° and 90° loading further demonstrates that both loading magnitude and direction influence the location and extent of stress concentration.

These findings provide biomechanical support for the concept of utilizing deeper basal cortical bone in severely atrophic maxillae. However, the results should be considered hypothesis-generating and should be validated through patient-specific FEA, experimental mechanical studies and prospective clinical investigations before definitive conclusions regarding implant survival or superiority over conventional implant therapy are made[12].

This study has several limitations. The analysis was based on a single three-dimensional atrophic maxillary model, and the findings may not represent variations in individual anatomy and bone quality. The bone was modeled using assumed material properties and was considered relatively homogeneous, whereas biological bone is anisotropic and heterogeneous. The analysis also used static loading conditions and did not fully reproduce complex functional and par functional forces, fatigue loading, or dynamic masticatory cycles. Furthermore, the finite element model does not account for biological factors such as bone remodeling, osseo integration changes, or individual patient-specific responses. Therefore, the results should be interpreted as biomechanical predictions rather than direct evidence of clinical implant survival.

Conclusion

The present finite element analysis demonstrated that stress distribution around basal implants is influenced by the magnitude and direction of loading. At lower and moderate loads, greater stress concentration was observed in the Crestal alveolar bone, whereas increasing loads resulted in greater stress transmission to the basal bone. These findings suggest that the deeper basal bone plays an important role in load-bearing and may provide biomechanical support for basal implants in severely atrophic maxillae. Further clinical studies are required to validate these findings and establish their long-term clinical relevance.

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