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Comparative Finite Element Analysis of Stress Distribution Between Bicortically and Monocortically Anchored Endosseous Implants Supporting a Mandibular Overdenture

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Abstract:

- ***Background:***

Mandibular implant-retained overdentures improve prosthetic stability, but the effect of bicortical implant anchorage on stress transfer remains incompletely characterized. This study compared the biomechanical behaviour of monocortically and bicortically anchored implants supporting a mandibular overdenture.

- ***Materials and Methods:***

Two three-dimensional finite element models of an edentulous mandible restored with a two-implant Locator-retained overdenture were analysed. Model 1 used 4.2 × 11.5 mm MIS Seven implants engaging the crestal cortex; Model 2 used 4.2 × 18 mm implants engaging both crestal and inferior cortices. The models were subjected to 100 N axial and 150 N oblique (30°) static loading. Von Mises stresses in implant, bone and prosthetic structures and overall displacement were evaluated descriptively.

- ***Results:***

Mean implant stresses were lower in the bicortical model (implant 1: 56.69 versus 233.33 MPa; implant 2: 59.82 versus 259.41 MPa). Mean denture-base, cortical-bone and gingival stresses were higher in the bicortical model, whereas cancellous-bone stress was lower. Mean overall displacement was approximately 0.3136 mm in both models.

- ***Conclusion:***

The longer bicortically anchored implant configuration reduced implant stress but redistributed loading to supporting tissues and the prosthesis, without materially changing overall displacement. Because implant length and cortical engagement varied together, their individual contributions cannot be determined from this simulation.

Keywords: *Bicortical Anchorage; Finite Element Analysis; Implant Biomechanics; Mandibular Overdenture; Monocortical Anchorage; Stress Distribution.*

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I. INTRODUCTION

Edentulism is associated with progressive alveolar ridge resorption, reduced masticatory efficiency, impaired prosthesis stability and adverse effects on oral function and quality of life. Conventional mandibular complete dentures are particularly susceptible to loss of retention and stability because of the limited supporting area and continuous resorption of the residual ridge [1–5].

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Implant-supported mandibular overdentures have consequently become an established treatment option for the edentulous mandible. Clinical and consensus literature has demonstrated that a two-implant mandibular overdenture can provide substantial improvements in retention, stability, masticatory function and patient satisfaction compared with a conventional complete denture [6–14]. The biomechanical behaviour of such prostheses, however, depends on implant position, implant dimensions, bone quality, attachment design, prosthesis geometry and loading direction [8–18].

Finite element analysis (FEA) provides a non-invasive computational method for investigating stress and deformation within complex implant–bone–prosthesis systems. By assigning material properties and controlled boundary conditions to a three-dimensional anatomical model, FEA permits evaluation of stress concentrations that cannot be directly measured clinically [8,17,18]. It has therefore been extensively used to investigate implant length, diameter, attachment systems, bone quality and loading conditions [16–24].

Bicortical anchorage is based on engagement of the crestal cortical plate together with a second cortical structure, such as the inferior cortical border of the mandible. Engagement of additional cortical bone can increase mechanical support and alter the pathway by which functional loads are transmitted through the implant and surrounding bone. Previous experimental and finite element investigations have reported biomechanical effects of implant length and apical cortical anchorage, although the magnitude and direction of these effects vary according to implant geometry, bone quality and loading conditions [16,17,29–35].

In the edentulous mandible, the potential value of bicortical anchorage is of particular interest where available crestal bone is reduced or cancellous bone provides limited mechanical support. Engagement of a denser inferior cortical plate may provide an additional stabilizing point and redistribute load away from the crestal region. At the same time, redistribution of load may increase stresses in other parts of the implant–prosthesis complex. Thus, a reduction in implant stress should not automatically be interpreted as a reduction in stress throughout the entire system.

Although bicortical fixation has been investigated in implant biomechanics, relatively limited work has specifically examined two-implant mandibular overdentures comparing monocortical and bicortical anchorage under standardized conditions. The present study was therefore undertaken to compare stress distribution and overall displacement in a mandibular overdenture supported by monocortically versus bicortically anchored implants using three-dimensional FEA. The null hypothesis was that anchorage configuration would not alter the distribution of von Mises stress or overall displacement within the modeled overdenture system.

II. MATERIALS AND METHODOLOGY

This in-vitro computational study used three-dimensional finite element analysis to compare the biomechanical behaviour of monocortically and bicortically anchored implants supporting a mandibular overdenture. Two standardized finite element models of an edentulous mandible restored with a two-implant Locator-retained overdenture were constructed. The models were analyzed under the same material properties, boundary conditions and loading protocol.

➢ *Construction of Three-Dimensional Models*

A three-dimensional edentulous mandibular model incorporating cortical bone, cancellous bone and gingival tissue was developed and standardized for both experimental configurations. Two implants were positioned in the interforaminal region. The prosthesis geometry and attachment arrangement were maintained across the models.

- Model 1 – monocortical anchorage: MIS Seven MF7-11420 implant, 4.2 mm diameter × 11.5 mm length, engaging the crestal cortical bone.
- Model 2 – bicortical anchorage: MIS Seven MF7-18420 implant, 4.2 mm diameter × 18 mm length, engaging the crestal and inferior cortical bone.

The two configurations therefore differed in both implant length and cortical engagement. This distinction is considered when interpreting the results and represents an important limitation of the study design.

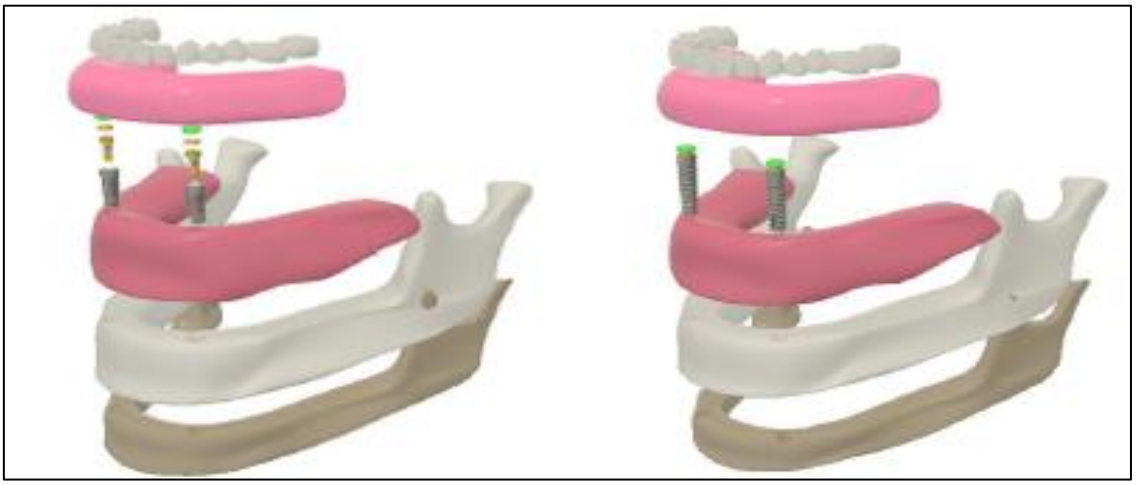


Fig 1 Three-Dimensional Mandibular Models Used for Monocortical and Bicortical Anchorage.

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➢ *Attachment and Prosthetic Design*

A Zest LOCATOR attachment system with a 3.75-mm cuff height was used in both models. The attachment assembly consisted of the Locator abutment, metal denture housing and nylon male insert. The overdenture incorporated an acrylic denture base and acrylic artificial teeth. Prosthetic components were standardized between the two models.

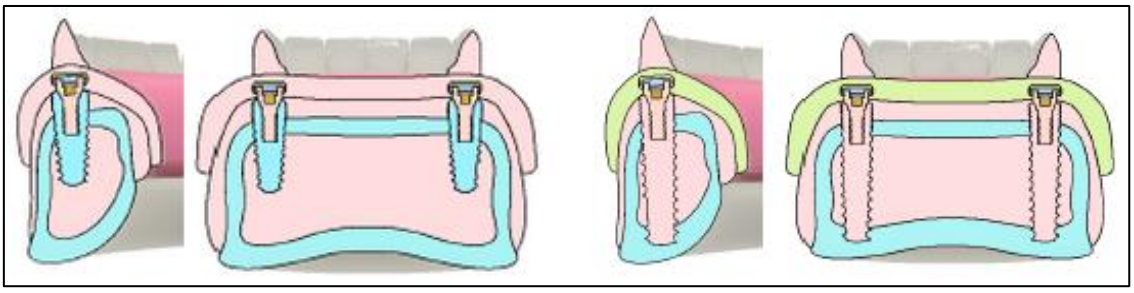


Fig 2 Implant Positioning and Cortical Engagement in the Two Configurations.

➢ *Software and Finite Element Model Generation*

Table 1 Software and Finite Element Model Generation

Procedure	Software
CAD modelling	Fusion 360
Solid modelling	SolidWorks 2017
Meshing	HyperMesh 2019
Finite element simulation	ANSYS 2019

The finite element models were discretized using first-order tetrahedral elements. A high-density mesh comprising approximately 2,327,609 elements and 1,615,085 nodes was generated. Mesh refinement was applied to critical regions including the implant–bone interface, peri-implant cortical bone and attachment components to improve the resolution of stress distribution.

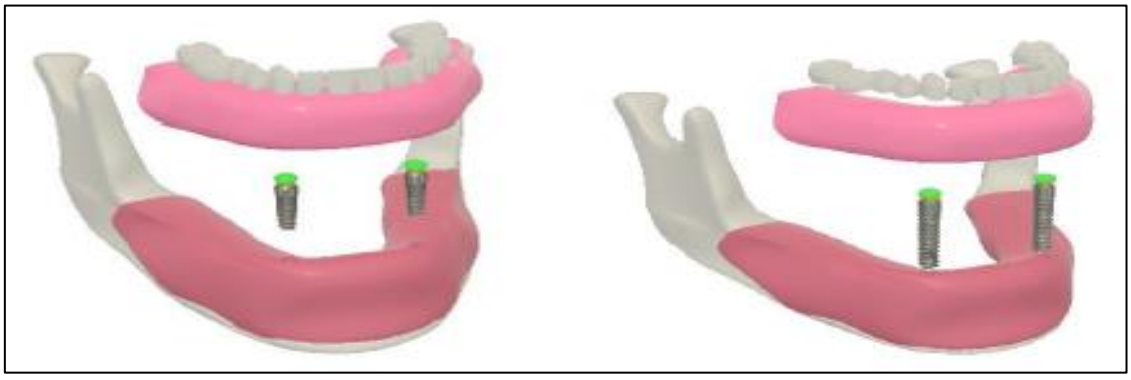


Fig 3 Final Mandibular Overdenture Assemblies for the Two Implant Configurations.

➢ *Material Properties*

Table 2 Material Properties

Component	Elastic Modulus (MPa)	Poisson's Ratio
Periodontal ligament	50	0.45
Cortical bone	13,700	0.30
Cancellous bone	1,370	0.30
Gingiva	3	0.45
Artificial acrylic teeth	2,940	0.30
Titanium dental implant	110,000	0.34
Locator abutment	103,000	0.35
Metal denture housing	200,000	0.30
Nylon male insert	2,500	0.30
Acrylic denture base	2,940	0.30
Cobalt–chromium framework	218,000	0.33

All materials were modeled as homogeneous, isotropic and linearly elastic according to the material-property assumptions used in the thesis.

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Fig 4 Finite Element Mesh of the Mandibular Overdenture Model.

➢ *Boundary Conditions*

- Inferior border of the mandible was fixed.
- Translational movements were restricted at the defined fixed region.
- The implant–bone interface was modeled as bonded, representing complete osseointegration.

➢ *Loading Protocol*

Table 3 Loading Protocol

Load Case	Magnitude	Direction
A	100 N	Vertical
B	100 N	Vertical
C	150 N	30° oblique
D	150 N	30° oblique

The formal methodology in the thesis specifies four load cases. The Results section presents the descriptive outcomes obtained from the finite element analysis without assigning unstated loading locations to individual cases.

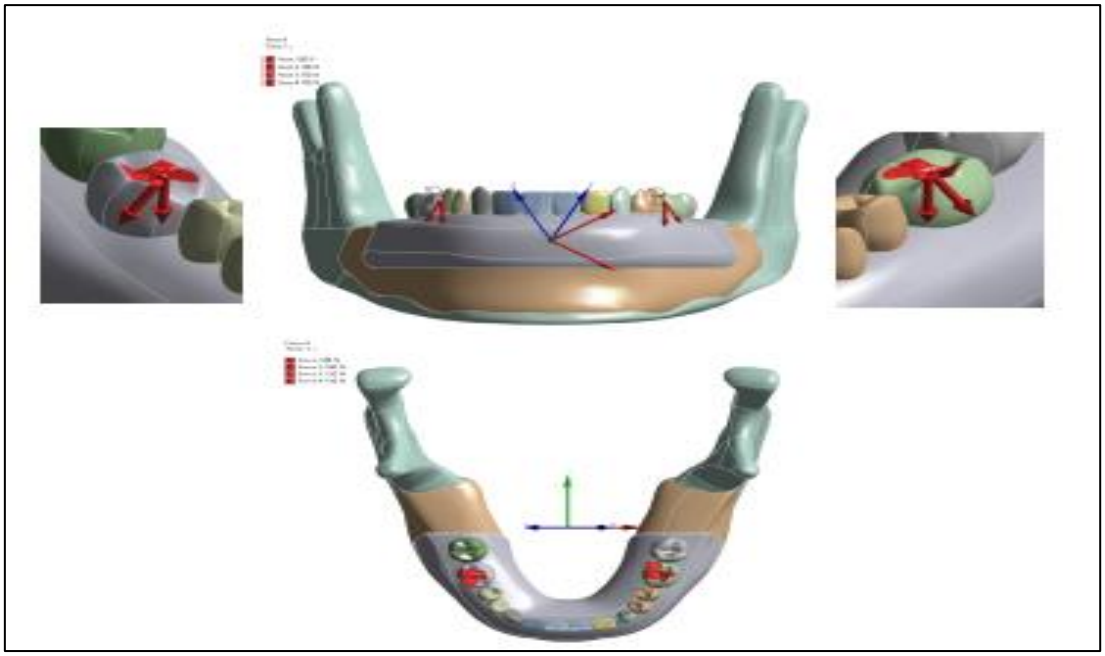


Fig 5 Loading Directions and Application Sites Used in the Finite Element Simulations.

➢ *Outcome Measures and Statistical Analysis*

Von Mises stress was evaluated in the implant components, cortical bone, cancellous bone, gingiva, acrylic denture base and artificial teeth. Overall structural displacement of the overdenture system was also evaluated. Descriptive statistics consisting of mean, standard deviation, minimum and maximum values were calculated using SPSS version 26.0. No inferential statistical test or p-value was reported in the thesis; therefore, comparisons in this manuscript are presented as descriptive differences in magnitude.

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III. RESULTS

The results demonstrated different stress-transfer patterns between the two anchorage configurations. The most pronounced difference was observed in implant stress, whereas overall displacement was essentially unchanged.

➢ *Implant Stress Distribution*

Table 4 Implant Stress Distribution

Implant	Model 1: Monocortical	Model 2: Bicortical
Implant 1, mean ± SD	233.33 ± 156.70 MPa	56.69 ± 37.92 MPa
Implant 2, mean ± SD	259.41 ± 174.34 MPa	59.82 ± 39.82 MPa
Maximum reported stress	518.71 MPa	119.01 MPa

Both implants showed substantially lower mean and maximum stress values in Model 2. The reduction was accompanied by lower variability, indicating a less concentrated stress pattern within the implant components in the bicortical configuration.

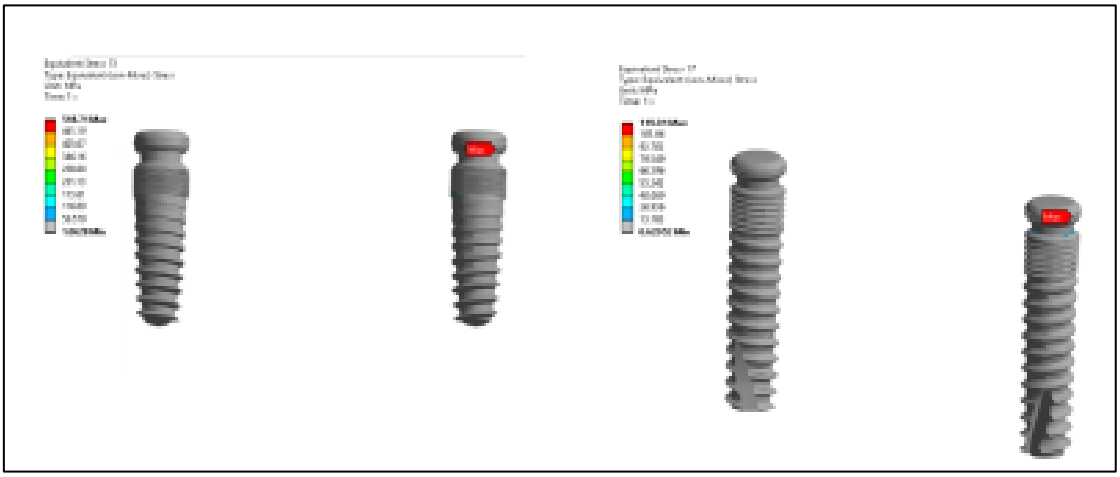


Fig 6 Von Mises Stress Distribution in Implants Comparing Model 1 and Model 2.

➢ *Artificial Teeth*

Mean stress in the artificial teeth was 8.539 ± 5.952 MPa in Model 1 and 9.709 ± 6.762 MPa in Model 2. The values were broadly comparable, although the bicortical model demonstrated a modest increase.

➢ *Denture Base*

Table 5 Denture Base

Parameter	Model 1	Model 2
Mean ± SD	173.344 ± 117.893 MPa	209.996 ± 142.846 MPa
Maximum	346.67 MPa	419.97 MPa

Stress in the denture base was higher in the bicortical model, indicating greater transfer of load to the prosthetic structure.

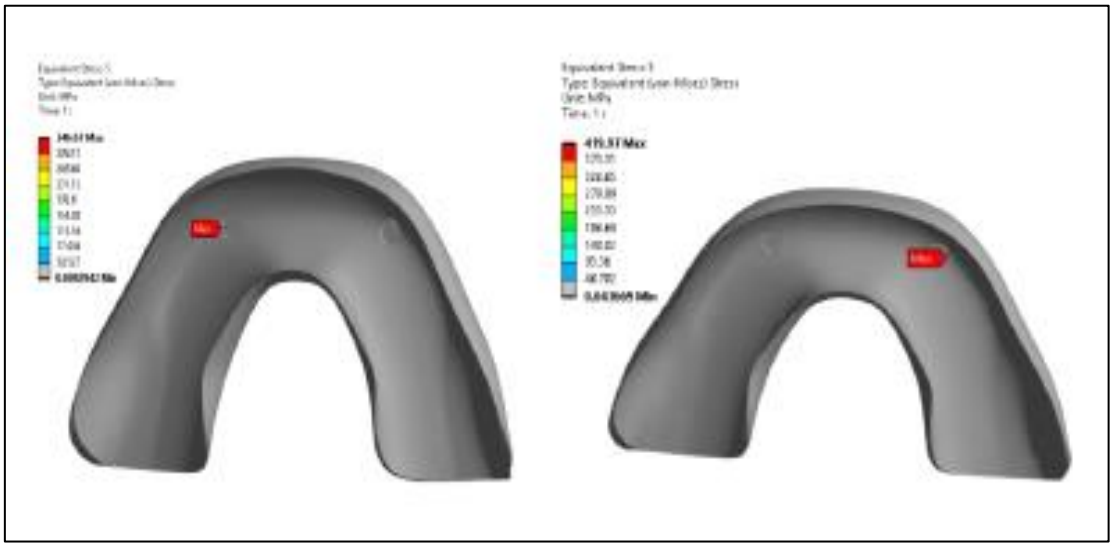


Fig 7 Von Mises Stress Distribution in the Denture Base (Model 1 vs Model 2).

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➢ *Cortical and Cancellous Bone*

Table 6 Cortical and Cancellous Bone

Structure	Model 1: Monocortical	Model 2: Bicortical
Cortical bone, mean ± SD	28.429 ± 19.385 MPa	30.925 ± 21.087 MPa
Cancellous bone, mean ± SD	3.287 ± 2.043 MPa	2.999 ± 1.864 MPa

Cortical bone stress increased modestly in Model 2, whereas cancellous bone stress decreased. The pattern is therefore consistent with redistribution of load toward the cortical structures rather than a uniform reduction in bone stress.

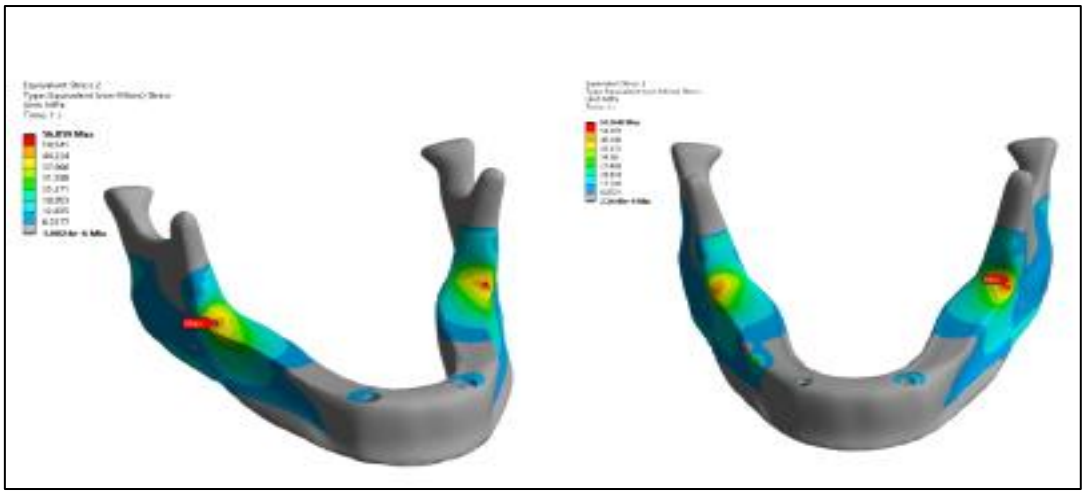


Fig 8 Comparative Cortical Bone Von Mises Stress Distributions in Model 1 and Model 2.

➢ *Gingival Stress*

Mean gingival stress increased from 0.377 ± 0.258 MPa in Model 1 to 0.578 ± 0.396 MPa in Model 2. This finding indicates increased transfer of load to the supporting soft-tissue region in the bicortical configuration.

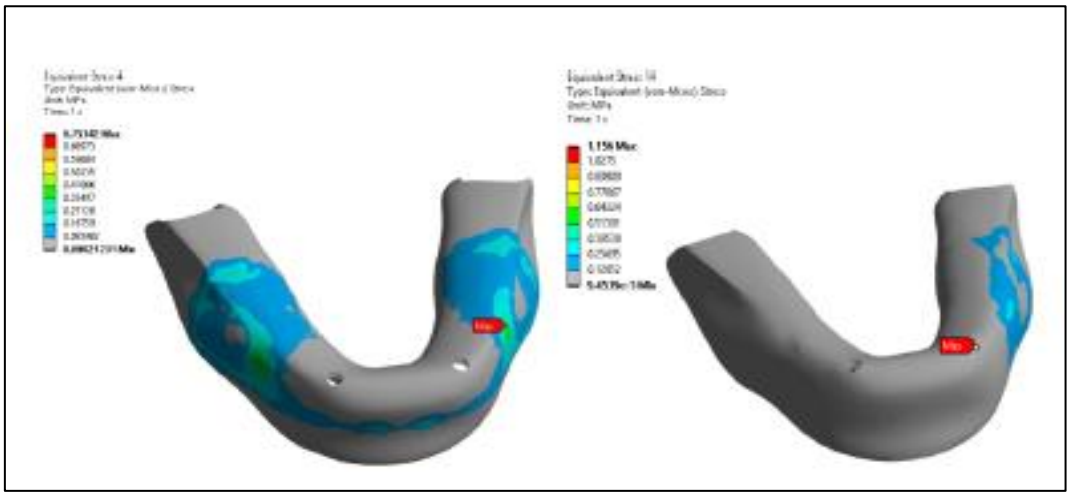


Fig 9 Comparative Gingival Stress Distributions in Model 1 and Model 2.

➢ *Overall Displacement*

Table 7 Overall Displacement

Parameter	Model 1	Model 2
Mean ± SD	0.3136 ± 0.2117 mm	0.3136 ± 0.2119 mm
Minimum	0 mm	0 mm
Maximum	0.6271 mm	0.6274 mm

Overall displacement was essentially identical between the two models. Thus, the change in anchorage configuration did not produce a meaningful difference in the global displacement of the modeled overdenture.

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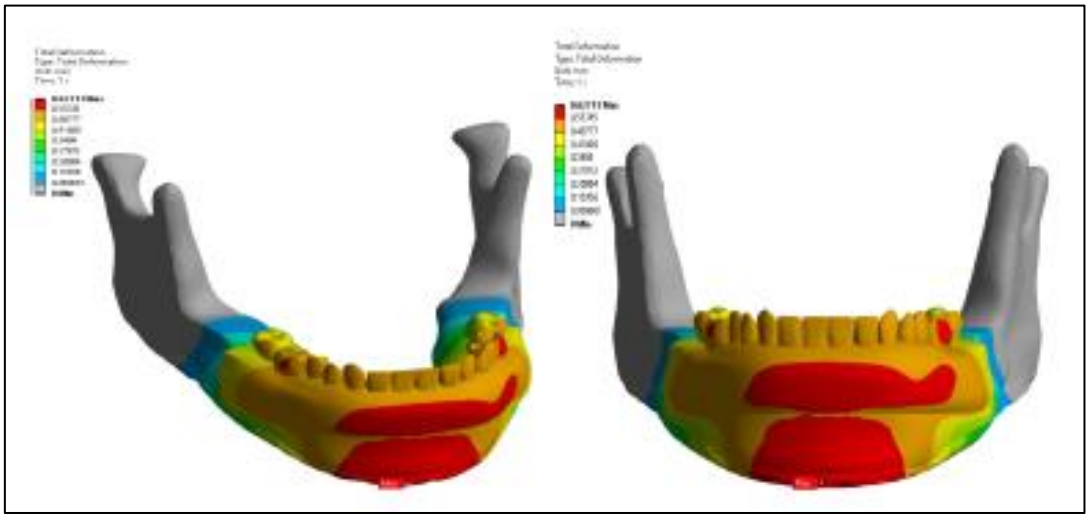


Fig 10 Comparative Total Displacement Contours of the Two Mandibular Overdenture Models.

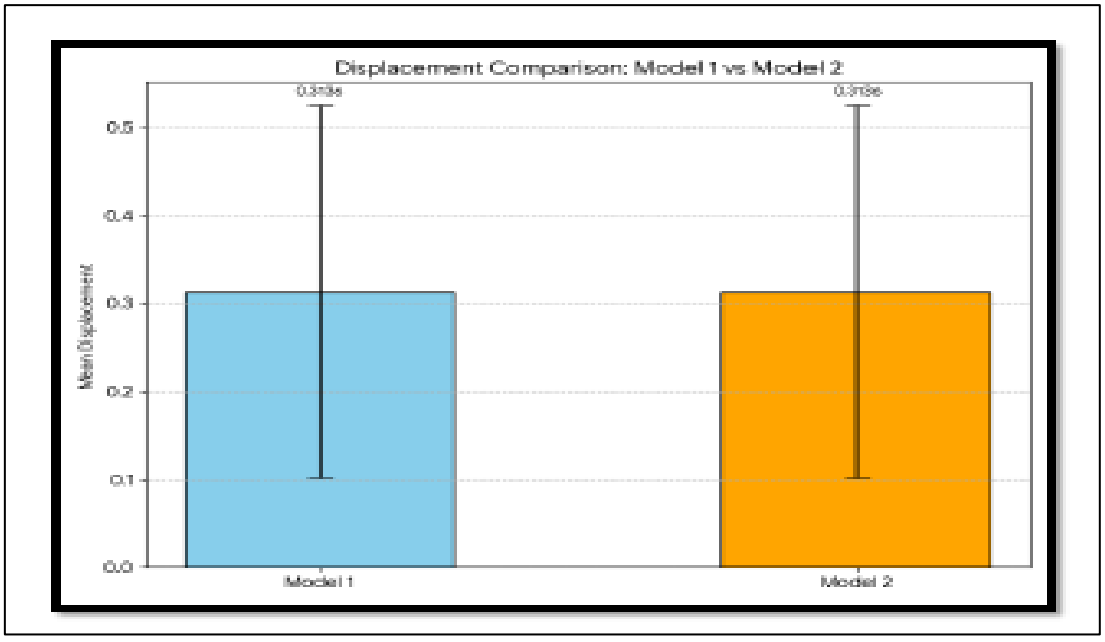


Fig 11 Mean Displacement Comparison Between Model 1 and Model 2.

IV. DISCUSSION

The present three-dimensional finite element analysis demonstrated that changing from monocortical to bicortical anchorage produced a marked change in the internal stress distribution of the implant-supported overdenture system. The most prominent finding was the reduction in implant stress in the bicortical model. Mean stress decreased from 233.33 to 56.69 MPa for Implant 1 and from 259.41 to 59.82 MPa for Implant 2. The maximum reported implant stress also decreased from 518.71 to 119.01 MPa. These findings are consistent with the biomechanical rationale that additional cortical engagement and greater implant length can increase mechanical support and distribute functional forces over a greater bone–implant contact area [16–18,29–35].

Stress concentration around the crestal region is a recurring finding in implant biomechanics because cortical bone is considerably stiffer than cancellous bone and therefore participates strongly in load transfer. Bicortical engagement provides a second cortical support point, potentially reducing bending and concentrating less of the applied load at a single coronal region. Previous investigations of implant dimensions and apical cortical anchorage have similarly emphasized the influence of cortical engagement and implant geometry on primary stability and stress transmission [16–18,30–35].

An important feature of the present results is that stress was not reduced uniformly throughout the system. Cortical bone stress increased from 28.429 to 30.925 MPa in the bicortical model, while cancellous bone stress decreased from 3.287 to 2.999 MPa. This opposing pattern supports the interpretation of load redistribution. Rather than eliminating stress, bicortical anchorage appears to alter the pathway through which load is transferred, shifting a greater proportion of load toward the stiffer cortical structures while reducing the demand placed on the cancellous compartment. This is biomechanically plausible because the inferior cortical border provides an additional rigid support region.

The increase in cortical stress should therefore be interpreted together with the reduction in implant and

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cancellous bone stress. A biomechanically favourable configuration cannot be defined solely by the lowest stress value in one component; the distribution of stress throughout the complete implant–bone–prosthesis system must be considered. The present findings demonstrate this principle particularly clearly because the bicortical model simultaneously showed lower implant and cancellous bone stress but higher cortical, denture-base and gingival stress.

The higher denture-base stress in Model 2 is also consistent with redistribution of occlusal load. Mean denture-base stress increased from 173.344 to 209.996 MPa, with maximum stress increasing from 346.67 to 419.97 MPa. In a two-implant overdenture, the implants provide retention and stabilization while a portion of functional loading continues to be transmitted through the denture base and supporting mucosa. Locator attachments permit limited rotational movement and resilience, allowing the prosthesis and its supporting tissues to participate in load sharing [19,20,28]. The present results suggest that the altered implant support produced by bicortical anchorage changed this load-sharing relationship.

Artificial tooth stresses were relatively similar between models, with mean values of 8.539 MPa and 9.709 MPa. The small difference suggests that the principal biomechanical effect of anchorage configuration occurred deeper within the implant–bone–prosthesis complex rather than as a major alteration in stress within the artificial teeth. Similar observations in overdenture studies have emphasized that attachment design, implant support and prosthesis geometry influence the way functional loads are distributed among individual components [7,9,19,20,28].

Gingival stress increased from 0.377 to 0.578 MPa in the bicortical model. Although the absolute values were low compared with implant and denture-base stresses, the direction of change is consistent with greater load participation by the supporting mucosal tissues. In an implant-retained overdenture, the residual ridge remains an important component of prosthetic support, particularly during unilateral or eccentric loading. Therefore, improved implant anchorage does not necessarily eliminate mucosal loading; instead, the balance between implant support and tissue support may be altered.

Overall displacement was almost identical in the two configurations. Mean displacement was 0.3136 ± 0.2117 mm in Model 1 and 0.3136 ± 0.2119 mm in Model 2, with maximum values of 0.6271 and 0.6274 mm, respectively. This indicates that the substantial reduction in implant stress did not translate into a detectable difference in global overdenture displacement. The result emphasizes that stress distribution and displacement are distinct biomechanical outcomes. A system can redistribute internal stresses without substantially changing its overall deformation.

The thesis discusses micromotion as an important biological consideration because excessive movement at the implant–bone interface may interfere with osseointegration. However, the numerical displacement reported in the present analysis represents overall structural displacement rather than a separately isolated measurement of implant–bone interfacial micromotion. Consequently, the present study should not be used to claim a specific reduction in implant micromotion or to compare the measured displacement directly with proposed biological micromotion thresholds.

Implant length is another important consideration. The bicortical model used an 18-mm implant whereas the monocortical model used an 11.5-mm implant. Implant length and cortical engagement were therefore changed simultaneously. The observed reduction in implant stress cannot be attributed exclusively to bicortical anchorage because increased implant length itself can increase bone–implant contact and alter stress distribution [16,31]. The findings should consequently be interpreted as the biomechanical effect of the complete modeled configuration rather than as an isolated effect of cortical engagement.

The loading protocol also affects interpretation. The thesis specified vertical and 30° oblique static loading conditions. Oblique loading is expected to introduce bending components and may increase localized stress compared with loading directed along the implant axis. Previous FEA studies have similarly demonstrated that loading direction, implant geometry and attachment design can substantially modify peri-implant stress distribution [8,17,18,22,23]. However, the present manuscript does not assign individual stress maxima to a particular load case unless explicitly documented in the thesis output.

The Locator attachment system used in both models is clinically relevant because of its low vertical profile, replaceable nylon insert and resilient behaviour. Attachment studies have demonstrated that attachment geometry and resilience can influence retention, prosthesis movement and load transmission [19,20,28]. Keeping the same attachment system in both models reduced one source of variation and allowed the anchorage configuration to remain the principal design difference.

Finite element analysis offers important advantages for comparative biomechanical studies because identical geometry, material properties and loading can be imposed on each model. Nevertheless, the findings are subject to the assumptions of the computational model. The present study treated the materials as homogeneous, isotropic and linearly elastic, although biological bone is heterogeneous and anisotropic. Complete osseointegration was assumed at the implant–bone interface, and static loading does not reproduce the complex magnitude, frequency and direction of clinical mastication.

The standardized mandibular geometry may also not represent the full range of individual anatomical variation in edentulous patients. In addition, the present design did not isolate the effect of implant length from bicortical engagement. Future investigations could use matched implant lengths with and without inferior cortical engagement, patient-specific CT-derived anatomy, heterogeneous anisotropic bone properties, nonlinear contact conditions, dynamic cyclic loading and experimental validation. Such studies would help determine whether the stress redistribution observed here translates into clinically meaningful differences in primary stability, marginal bone response or prosthetic complications.

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V. CONCLUSION

Within the limitations of this three-dimensional finite element analysis, bicortical anchorage produced substantially lower stress within the modeled implant components and slightly lower cancellous bone stress than the monocortical configuration. In contrast, cortical bone, denture-base and gingival stresses were higher, indicating redistribution rather than uniform reduction of load throughout the system. Overall displacement was essentially identical between the two models. The findings therefore suggest that bicortical anchorage changes the pathway of force transmission and reduces implant stress, but its biomechanical effect should be interpreted in relation to the complete implant–bone–prosthesis system. Because implant length and cortical engagement were changed simultaneously, further controlled and experimental studies are required to isolate the independent contribution of bicortical anchorage.

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DECLARATIONS

- *Ethical Approval:*
  Not applicable to the computational in-vitro finite element study.

- *Informed Consent:*
  Not applicable.

- *Funding:*
  No external funding was reported in the thesis.

- *Conflict of Interest:*
  No conflict of interest was reported in the thesis.

- *Generative AI Disclosure:*
  Generative artificial intelligence tools were used to assist with manuscript organization and language editing. The authors retain responsibility for the scientific content, interpretation of the finite element results, accuracy of the data and final manuscript.

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