



A Comparative Evaluation of Influences of Corticobasal Implants and Different Framework Materials on Stress Distribution in Bone: A Three Dimensional Finite Element Analysis Study

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Basal Implants, Immediate Loading, MOT Implant, PEEK, Zirconia

ABSTRACT:

Purpose: The purpose of this study is to compare the influences of Corticobasal implants and different Framework materials on Stress distribution in bone when using a three dimensional finite element analysis.

Methods: A three dimensional model of a human mandibular bone based on measurements of a dried human edentulous mandible fabricated using finite element analysis modeling software. Models are created to evaluate the stress distribution around bone and in Corticobasal Implants using 8 implants with Two different framework materials Zirconia and PEEK. An Axial and oblique loads were applied on the implants for these finite element models and results are analysed using finite element analysis.

Results: The overall stress values observed for Group-I corticobasal implants with PEEK prosthesis during axial load of 100N anteriorly & 200N posteriorly was 375.5 Mpa, during non-axial load of 30N anteriorly & 30N at 15° posteriorly was 87.719 Mpa and for Group-II corticobasal implants with Zirconia prosthesis during axial load was 125.882 Mpa, during non-axial load was 38.0109 Mpa.

Conclusions: This finite element comparative study found that PEEK showed lower internal stress within prosthesis framework but transferred greater stress to surrounding bone and implants and corticobasal implants with zirconia framework resulted in lower implant stress values with superior biomechanical performance.

Introduction

Implants are most commonly used for replacing single teeth, for partial missing teeth and also in complete edentulous conditions. In contemporary dentistry, the use of crestal implantology to replace missing teeth, where implants are positioned within the crestal alveoli has become a standard and reliable procedure¹. While this approach has demonstrated considerable success, certain limitations such as prolonged healing times, insufficient bone volume, and susceptibility to resorption made these crestal implants limited to ideal bone requirements.

A minimum vertical bone height of 10 to 13 mm is necessary for optimal implant placement². If the available bone height is insufficient in edentulous areas, surgical procedures are required to restore the alveolar bone dimension and facilitate successful implant placement³. In conditions like severely resorbed ridges and poor quality of crestal bone additional surgical procedures are required for placement of conventional implants⁴.

In order to overcome these additional surgical procedures, cortico-basal implants are introduced to engage the highly mineralized basal bone of jaw⁵. This



unique approach enhances primary stability and allows for immediate functional loading. Basal implants can be considered in cases of failed bone augmentation procedures and also suitable for patients with thin ridges, inadequate buccolingual bone thickness, or insufficient bone height⁶.

The restorative material for fabrication of implant supported prosthesis is an additional influence factor for stress distribution on implants, components, retention screw, and adjacent bone tissue. Prosthetic restorations designed by using different framework materials also play an important role in stress distribution on implants and surrounding bone⁷.

Finite element analysis (FEA) is a numerical method of analyzing the stresses and deformations in structures of any given geometry and allows researchers to predict stress distributions in the cortical and trabecular bones, implants and abutments, and prostheses⁸. The stress distribution within the mandible and implants are evaluated using static structural analysis. By applying material properties, boundary conditions, and external forces, the software calculates stress distribution throughout the model and the results help in identifying stress concentration zones, failure risks, and potential areas for design improvement⁹.

FEA has been widely employed to study implant biomechanics, as it allows for precise simulation of real-world forces and interactions between implants, bone, and prosthetic components¹⁰.

The aim of this study is to assess the influences of corticobasal implants and different framework materials on stress distribution in bone using a three dimensional finite element analysis.

Materials and Methods

FEA is a numerical simulation technique to analyze biomechanical performance of Implants and stress distribution in Implants and surrounding bone. A finite element model is constructed by breaking down solid objects into multiple interconnected components, each sharing common nodes. These elements are assigned material properties that correspond to the characteristics of the object being analyzed. The interaction among degrees of freedom, including displacements and forces within the structure under load, is represented using triangular or quadrilateral elements in a mathematical matrix. All the details about material properties, applied loads, boundary conditions, and other relevant

attributes, alongside information about elements and node were included in this model.

In this study, detailed 3D models of the mandible, implants, and prosthetic components were developed using **SolidEdge V19**. These anatomical models were then imported into **ANSYS R18.1** to simulate mechanical loading conditions and assess stress distribution patterns.

Mandible and prosthetic components were discretized into a network of small elements connected by **nodes**, the critical points at which calculations are performed. Each node in a three-dimensional model possesses six degrees of freedom: three translational (along x, y, and z axes) and three rotational (about the x, y, and z axes). These nodes are strategically positioned to capture complex geometry and load-bearing regions of the jaw and implant system. As more nodes are present, the finer will be the details leading to higher accuracy. For representing the materials in the study, each material has unique properties like poissons ratio and modulus of elasticity and each element is allocated with these characteristics. Each node records displacement and stresses, ANSYS R 18.1 software evaluates how nodes move and interact under various loads. Based on these nodal displacements, von mises stress and other stresses are calculated for the entire model.

System configuration:

For the study, computer with following sytem specifications was used:

1. INTEL CORE i 7-PROCESSOR
2. 16 GB RAM
3. Hard disk: 1 TB
4. Display: LED Monitor, 21 inch
5. Windows: 8
6. Solid Edge V19 -Modelling software
7. Hypermesh V11 –Meshing software
8. Ansys18.1 - Analysis software
9. Keyboard
10. Mouse



Geometric model of Mandible:

A geometric model of the mandibular body was created (fig 1) using the dimensions of a dried edentulous human mandible.

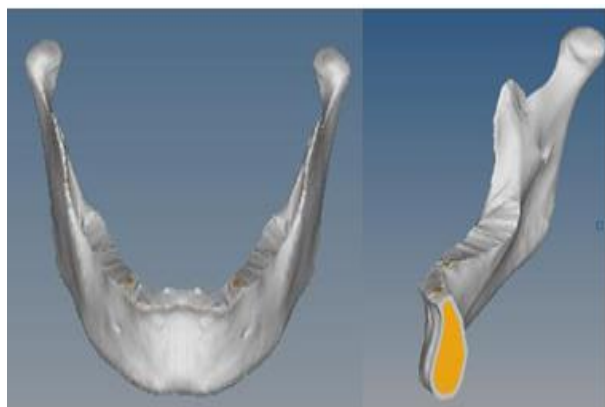


Figure 1: Geometric model of mandibular bone

Implants:

Eight corticobasal Implants (fig 2) were placed. Four in anterior region, one implant in lateral incisor region bilaterally, One Implant in canine region bilaterally & and four in posterior region, One Implant in first premolar region bilaterally & One Implant in first molar region bilaterally.



Figure 2: MOT Implant

MOT IMPLANT (Monoimplant)

Anterior Implants

- Length of the implant : 14 mm
- Diameter of the implant : 3.5 mm

Posterior Implants

- Length of the implant : 12 mm
- Diameter of the implant: 4.0 mm

Framework prosthesis:

Two different prosthesis materials were fabricated.

- PEEK
- ZIRCONIA

Material Properties:

The properties of various materials used in the study are listed in (Table 1).

Materials	YOUNG'S MODULUS (MPa)	POISSONS RATIO
Titanium implant	110000	0.35
Cancellous bone	1370	0.30
Cortical bone	13700	0.30
PEEK	3400	0.4
Zirconia	210000	0.3

Table no: 1 Mechanical properties of materials.

The material is considered uniform throughout, with identical mechanical properties across the entire structure (HOMOGENEITY) and in all directions material properties are same (Isotropy); the deformation or strain in the structure is directly proportional to the applied force and does not depend on the strain rate (Linear Elasticity). All these mechanical properties are standardized. The implants were assumed to be osseointegrated, meaning a perfect bond between bone and implant was considered (clinical scenario was taken into consideration).

Loads applied:

- Axial loads of magnitudes 100N & 200N were applied in anterior & posterior region respectively during uniform bilateral biting are directed downwards parallel to long axis of the implant.
- Non-Axial loads of magnitudes 30N & 30N at 15° were applied in anterior & posterior region respectively as lateral movements from the long axis of the implant.



For ease of analysis models are categorized into 2 groups (Table 2):

- **Group 1** consists of Corticobasal implants with PEEK framework prosthesis models in which axial load & non – axial loads are applied.

- **Group 2** consists of Corticobasal implants with ZIRCONIA framework prosthesis models in which axial load & non – axial loads are applied.

GROUPS	MODELS
Group-I PEEK Framework	Axial loading
	Non-axial loading
Group-II ZIRCONIA Framework	Axial loading
	Non-axial loading

Table No: 2 shows groups into which models are characterized.

Stresses:

Stresses and nodes are closely related in finite element analysis study as the nodes represent the points where the model is divided into smaller elements and each element has set of nodes and stresses are calculated at these nodes. By analysing stresses at different nodes, areas which are under excessive load in prosthesis framework and implant can be identified and those stress concentrations indicate weakness points, which helps to ensure better durability. A total of 485,283 elements and 576,233 nodes were employed in this study.

RESULTS

When an axial load of 100N (anterior) & 200N (posterior); non-axial loads of magnitudes 30N (anterior) & 30N at 15°(posterior) was applied onto PEEK and ZIRCONIA framework prosthesis.

Evaluation of stress distribution in bone, Implants & framework prosthesis was done for 4 models.

For all the models Overall Deformation(mm), Overall Stress (MPa), Cortical Stress (MPa), Cancellous Stress

(MPa), Implants Stress (MPa), Framework prosthesis Stress (MPa) were studied (Table 3).

Table No: 3 shows values of Group-I & II models.

Details	Peek (Group-I)		Zirconia (Group-II)	
	Axial Load	Oblique Load	Axial	Oblique
Overall displacement	1.07917	0.423582	1.12092	0.397862
Overall Stress	375.5	87.719	125.882	38.0109
Cortical stress in the region of implants	153.943	38.805	41.7212	9.49714
Cancellous Stress in the region of Implants	5.10916	0.815721	3.42711	0.570251
Lateral Implant stress	71.7428	13.4008	35.2067	9.89017
Canine Implant stress	50.293	17.3953	23.8251	8.74809
Premolar Implant stress	161.125	43.8754	23.602	11.8695
Molar Implant stress	362.479	87.719	113.994	38.0109
Prosthesis framework Stress	14.1298	3.51384	63.7007	21.6273

DISCUSSION

Basal implants are placed in basal bone of jaw, which is less prone to infections and basal bone doesnot undergo resorption over time like crestal bone. The dense cortical basal bone provides excellent support for implants¹¹. Ideally for completely edentulous patients eight to ten basal implants need to be placed for rehabilitation in the mandible and for maxilla ten to



twelve basal implants are required for full mouth rehabilitation¹². Basal implants have different modifications in surfaces like polished, rough surface implants and combination of both like MOT from Monoimplant system.

Cochran DL in 1999 concluded that rough surfaces demonstrate greater bone-to-implant contact and higher success rates, especially in partially edentulous patients and in select maxillary cases¹³.

Sirandoni D in 2019 found that non-polymeric frameworks produced stress levels within the physiological limits of bone. The most favorable outcomes were observed with titanium (Ti), cobalt-chromium (Co-Cr), zirconia (ZrO₂) frameworks in implant-supported fixed mandibular prostheses¹⁴.

In the present study on corticobasal implants in the mandible, zirconia prosthesis showed maximum displacement (1.12092 mm), while PEEK prosthesis showed minimum displacement (1.07917 mm) under axial loading. The minor difference in these displacement values suggests that both materials can be used for load bearing Implant supported prosthesis.

Cortical bone stress in implant region is a crucial factor for longevity of implants. This study found higher cortical stress with PEEK prosthesis (153.943 MPa) compared to zirconia (41.7212 MPa) under axial load, suggesting greater risk of bone resorption and implant failure with PEEK. Zirconia showed better stress distribution, reducing excessive bone loading.

Similarly, cancellous bone stress was observed to be lower in Implants with Zirconia framework (3.42711 MPa axial, 0.570251 MPa oblique) compared to PEEK (5.10916 MPa axial, 0.815721 MPa oblique). As cancellous bone structurally weaker than cortical bone, higher stress levels contribute to severe bone loss or Implant failure. The lower stress levels in Zirconia supported implants suggest improved biomechanical compatibility, reducing risk of long-term complications.

Implant stress is an important factor, which influences the success of corticobasal implants. The study revealed that Implants with Zirconia frameworks resulted in lower implant stress values (113.994 MPa axial, 38.0109 MPa oblique) compared to implants with PEEK framework (362.479 MPa axial, 87.719 MPa oblique). Among individual implant sites, as masticatory forces are more concentrated in posterior region, Implants in the molar region experienced the

highest stress values in both materials. However, Basal Implants with Zirconia prosthesis consistently exhibited lower stress magnitudes, indicating better force distribution and reduced localized stress concentrations. Lower implant stress will enhance implant stability and reduces the likelihood of implant loosening or failure. Within the framework prosthesis, Framework stress was significantly higher in Zirconia framework (63.7007 MPa axial,) compared to PEEK framework (14.1298 MPa axial).

This finding indicates that PEEK absorbs more stress due to its lower modulus of elasticity, which may contribute to improved patient comfort. However, excessive stress in the framework could lead to material fatigue over time, potentially impacting the durability of the prosthesis. The selection of framework material plays a crucial role in overall success and longevity of corticobasal implants.

While PEEK framework offers superior shock absorption and flexibility, it transmits high levels of stress to cortical and cancellous bone around implants. This increased stress may accelerate bone resorption, loss of osseointegration and leads to implant failure, making PEEK less ideal for long-term use. However, its lower internal stress levels within PEEK framework suggest better resistance to material fatigue and fractures potentially improving patient comfort during function.

In contrast, Zirconia framework distributes occlusal forces more evenly across implant and bone interface, minimizing the stress concentrations in both cortical and cancellous bone around implants. This characteristic makes it a more favorable choice for long-term stability, as it reduces the chances of bone resorption and Implant-related complications. However, because of its high rigidity, Zirconia framework prosthesis may lack the ability to absorb shock effectively, which might lead to slightly increased forces being transmitted to implant and bone during mastication. Despite this superior mechanical strength and fracture resistance of Zirconia make it a reliable option for patients requiring a long-lasting prosthesis.

Ultimately, the decision between PEEK and Zirconia should be guided by the specific clinical scenario, patient preferences, and biomechanical demands.

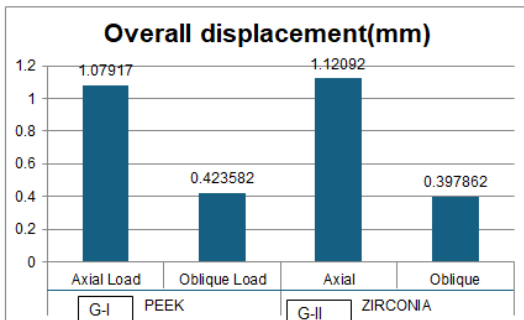


Fig 3: Overall displacement under axial load and oblique load.

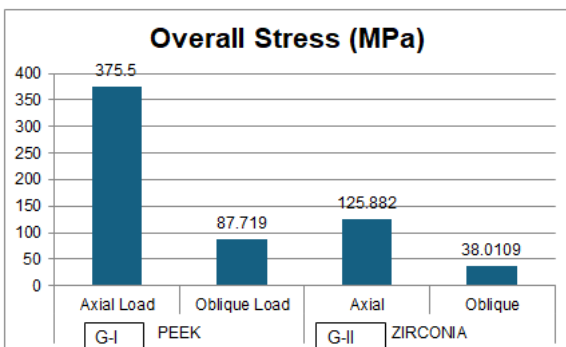


Fig 4: Overall stress under axial load and oblique load

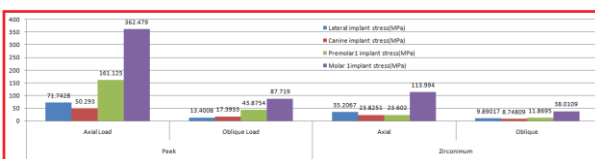


Fig 5: Implants stress under axial load and oblique load

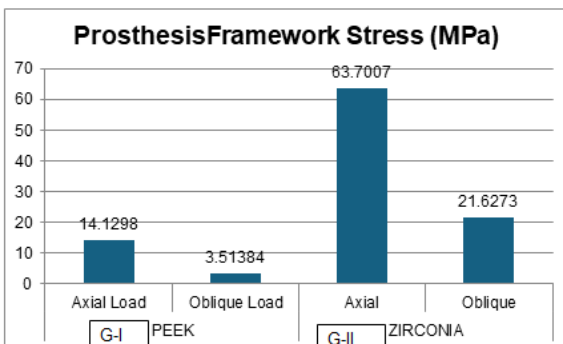


Fig 6: Overall prosthesis framework stress under axial load and oblique load.

LIMITATIONS OF STUDY

Finite Element Analysis (FEA) is a numerical method used to evaluate structural behaviour, but its application to biological systems has limitations. Living tissues are

complex and cannot be fully represented by fixed mathematical models. While FEA offers valuable insights, it cannot capture complete biological responses. Therefore, experimental studies and clinical trials are essential to validate simulations and ensure their clinical relevance.

CONCLUSION

Based on the results, it was concluded that corticobasal implants with Zirconia framework prosthesis are biomechanically more favourable in minimizing stress around bone and implants.

The following conclusions can be made within the parameters of the study:

1. Corticobasal Implants with Zirconia framework prosthesis exhibited superior biomechanical performance compared to PEEK under axial and non-axial loading.
2. Lower stress concentrations were observed with Zirconia framework in cortical & cancellous bone reducing the risk of bone resorption.
3. Implants with PEEK framework prosthesis exhibited higher stress concentrations in cortical & cancellous bone and also around Implants which may compromise implant longevity.
4. Within framework prosthesis, PEEK exhibited lower internal stress compared to Zirconia, indicating its flexibility and lower modulus of elasticity. But it resulted in greater stress transfer to surrounding bone and Implants.
5. Zirconia exhibited more internal stress within framework; thereby it reduced stress transfer to surrounding bone and implants.

To Conclude, Zirconia is recommended as framework material of choice in full arch rehabilitations with corticobasal Implants.

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DECLARATION OF CONFLICT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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