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Effect Of Two Different Reinforced Denture Base Materials On The Stresses Induced On Supporting Structure Of Implant Supported Mandibular Overdenture (In Vitro Study)

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Abstract:
Objective: *to compare the stresses induced by cobalt chrome metal reinforced overdenture bases versus PEKK-reinforced ones the supporting structures of implant supported mandibular overdenture using finite element method.*
Materials and Methods: *The present study included construction of an edentulous mandible with two implants in the canine region. On these models, the dentures were fabricated using conventional heat cure acrylic, reinforced with Co-Cr, heat cure acrylic reinforced with BioHPP. These models were then subjected to Finite Element analysis.*
Results: *The results showed that higher concentrations of von Mises stress were observed in the BioHPP superstructure with lower stress transfer on ball attachment compared to the Co-Cr framework, and the analysis of Maximum Principal Stress, revealed that the BioHPP framework exhibited a more favorable distribution of maximum principal stress across the compact compared to the Co-Cr framework.*
Conclusion: *From biomechanical point of view, BioHPP frameworks exhibited more favorable outcomes than Co-Cr frameworks in implant supported overdentures.*

Keywords: *implant supported over denture, BioHPP, Co-Cr.*

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I. Introduction:

Edentulism is defined as the complete loss of all dentition and it is a worldwide phenomenon.(1) Edentulism negatively influences not only oral function, but also social life and day-to-day activities.(2) Edentulous patients who use complete dentures often experience problems such as pain, discomfort, insufficient stability of denture during mastication and looseness of their dentures. Furthermore, residual ridge supported by complete denture becomes unstable by time because of gradual resorption of the ridge.(3)

Implant-Supported Overdenture (ISOD), is a complete denture that is usually supported on 2 or more implants in the anterior zone. ISODs are an effective, predictable and reliable treatment option, often indicated in cases where the prosthesis has suboptimal retention and stability. An ISOD confers a significant improvement in biting force and chewing efficiency. ISODs have also been shown to improve speech and confer other psychological benefits, emotional wellbeing and overall quality of life.(4)

Poly methyl methacrylate (PMMA) is one of the most widely used materials for fabricating dentures.(5) Though it has its success in meeting esthetic requirements, it is still far from ideal to meet mechanical requirements of a denture. One frequent problem that occurs with heat cured acrylic resin in overdenture prostheses is fracture. Eventual fracture of acrylic resin denture base occurs due to initiation and propagation of cracks from areas of high stress concentration over the abutments.(6,7)

Several approaches were attempted to strengthen the acrylic base using different methods and materials. The aim was to improve the impact strength, fatigue resistance and transverse strength of acrylic resin.(8)

Denture base reinforcing materials are generally classified into Non-metallic bases and metallic bases. Metallic bases include gold or cobalt-chrome-molybdenum or cobalt-chrome alloy dentures that are stronger, have greater resistance to fatigue and are less likely to break under normal conditions.(9)

The PEKK and polyether-ether-ketone (PEEK) are the two most well-known of the polyaryl-ether-ketone (PAEK) family. Polyether-ketone-ketone (PEKK) is the most recent evolving polymeric material in dentistry.(10)

Finite Element Analysis (FEA) was used to analyze distribution of stress in the components of dental prostheses and their supporting structures. FEA was regarded to be the ideal method for stress analysis as the components of the implant bone system, attachment devices and prosthesis are geometrically complex, FEA was regarded to be the ideal solution for such problem as it divides the problem domain into a collection of much smaller and simpler elements, each can be described with a relatively simple set of equations. As the set of elements would be joined together to build the whole structure, the equations describing the individual element's behavior are joined into an extremely large set of equations that is solved by the computer describing the behavior of the whole structure(11–13)

Although many researches have been published evaluating the generalized effect of overdenture attachment on the lower denture and supporting structures, little attention was directed to the effect of denture base materials on the overdenture supporting structures.

So this study was conducted to evaluate the effect of the reinforcement of the denture base with two different materials on the stresses induced on implant supported mandibular overdenture.

II. Materials And Methods:

Two 3-dimensional (3D) finite element models of an edentulous mandible that was rehabilitated with 2 interforaminal implants placed at the canine region were constructed with different overdenture base materials, one of them was reinforced by cobalt chromium alloy and the other one was reinforced by polyether ketone.

The 3D Finite element model was constructed by high-resolution computed tomography (CT) scan of a fully edentulous mandible and The Mimics software (Materialise, Belgium) was utilized for segmentation and 3D reconstruction of the anatomical structures, including the mandible, surrounding tissues, and implant sites. Then, the segmented 3D model was exported in STL format for further refinement in Geomagic Design X. This step involved smoothing surfaces, correcting geometric errors, and ensuring that all parts are anatomically accurate. All solid parts (implants, bone, ball attachment) were imported into the Solidworks software and manually assembled.

Implant Insertion was done via a refined 3D model of a Zimmer implant (4.1 mm diameter, 10 mm length) that was exported from BlueSkyBio software as an STL file. After that, the overdenture framework was seated on the ball attachment, and the acrylic shell was fitted over the framework to complete the prosthesis assembly and 2 models were constructed (**Model 1**) acrylic overdenture base reinforced with PEKK mesh and (**Model 2**) acrylic overdenture base reinforced with Cobalt-Chromium (Co-Cr) Framework. In both models, the ball attachment system was used to retain and stabilize the prosthetic structure.

The finite element analysis (FEA) was conducted using Mechanical APDL ANSYS 18.2 software (ANSYS, Canonsburg, PA, USA) to simulate the biomechanical performance of the implant supported over denture with different framework materials. The analysis included three main phases:

Pre-Processing Phase:

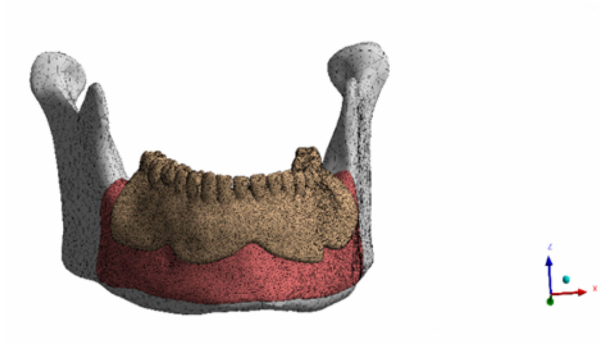
The prosthetic models were meshed using the ten node tetrahedral elements (Element type: Solid 187 in ANSYS) to accurately represent the geometry and material interactions of the implant and prosthetic components. Each component in the model including compact bone, cancellous bone, implants, ball attachments, framework, acrylic superstructure, nylon rubber, and gingiva, was assigned according to the materials' properties according to isotropic, homogeneous, and linear elastic assumptions. The modulus of elasticity and Poisson's ratio for each material are listed below:

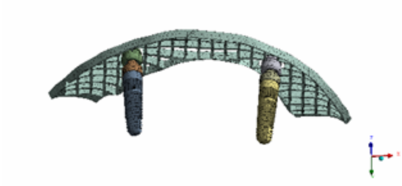
Table 1: Material properties

Material	Modulus of Elasticity (GPa)	Poisson's Ratio
Titanium Alloy (Implants)	110	0.35
Compact Bone	13.7	0.30
Cancellous Bone	1.42	0.30
Cobalt-Chromium (Co-Cr)	220	0.30
BioHPP (Polymer)	4.0	0.35
Acrylic Resin	2.77	0.30
Nylon Rubber (Ball Attachment)	0.05	0.40
Gingiva (Soft Tissue)	0.001	0.49

Regarding interfaces: **Bone-Implant Interface** was modeled with a bonded, no-separation contact to simulate rigid fixation between the implants and surrounding bone. **Ball Attachments and Framework**: (BioHPP or Co-Cr) was defined using a slip (no penetration) contact interface to simulate realistic movement between the components while the **Gingiva and Acrylic Superstructure**: was modeled with a no-separation contact condition, ensuring a secure attachment that transmits forces realistically.

A parabolic tetrahedral mesh was generated with fine elements around the implants and peri-implant bone (element size ~0.2 mm), and a coarser mesh for the soft tissue regions. The total number of nodes and elements were documented for both framework models to ensure uniform analysis conditions.

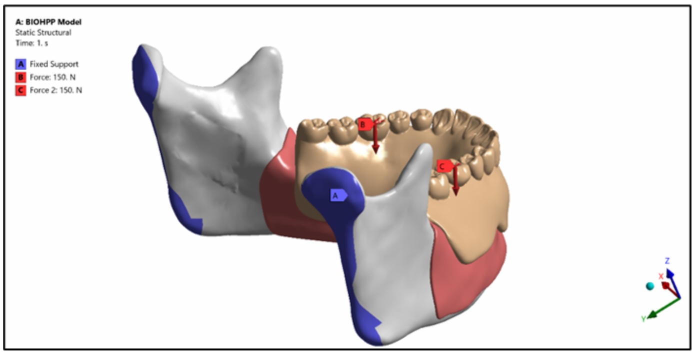


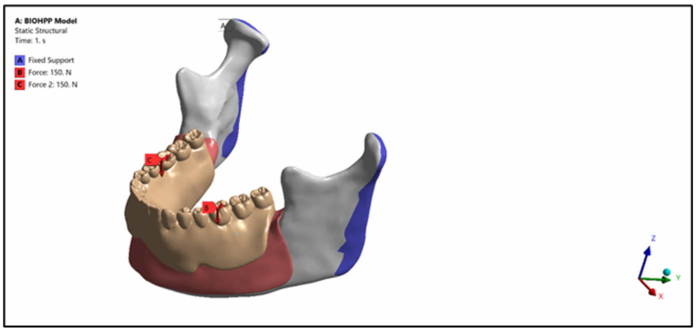


Case	Nodes	Elements
Acrylic overdenture base reinforced with pekk mesh	972419	615601
Acrylic overdenture base reinforced with co-cr mesh	972813	615780

Solution Phase:

An axial force of 150 N was applied bilaterally on the central fossa of the 1st molar to simulate functional loading during mastication. This force was intended to reflect the typical masticatory stresses experienced by the prosthesis and fixed restraints was applied at the condylar zones of the mandible to prevent any displacement in these regions during loading.





The forces transmitted through the implants, ball attachments, nylon rubber, and gingiva were recorded, tracking stress in both framework models (BioHPP and Co-Cr).

Post-Processing Phase:

Stress distribution maps for **maximum principal stresses** were generated specifically for compact and cancellous bone to identify regions at risk of high stress concentrations. **Von Mises stress** maps were utilized for the implants, prosthetic framework, nylon rubber ball attachments, superstructure and gingiva allowing for a detailed assessment of stress distribution across these components.

The maximum principal stress patterns in the **peri-implant bone** (both compact and cancellous) were compared between the **BioHPP** and **Co-Cr** frameworks. Special attention was given to the potential risks for stress-induced bone resorption or implant failure based on the observed stress distributions in the bone.

III. Results:

A detailed comparison of stress distribution in the mandible for both **BioHPP** and **Co-Cr** frameworks under axial loading conditions, focusing on the effects of nylon rubber at the ball attachments and gingival interfaces.

Axial Loading:

The analysis revealed that the **BioHPP** framework generated more favorable stress distributions in the compact and cancellous bone surrounding the implants, with maximum principal stresses of (7.3934 MPa) and (5.59 MPa), respectively. In contrast, the **Co-Cr** framework displayed maximum principal stresses of (7.391 MPa) for compact bone and (5.5926 MPa) for cancellous bone, indicating a slightly higher stress concentration.

Gingival Interface:

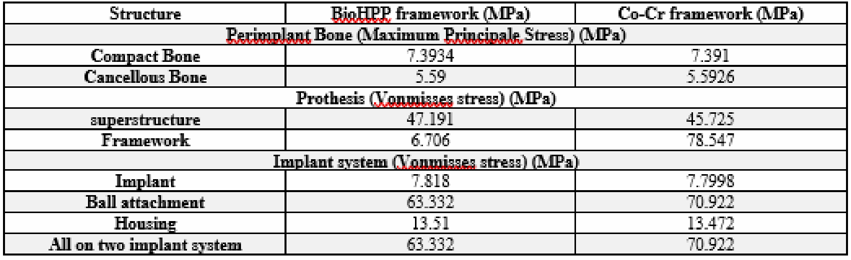
The presence of nylon rubber ball attachments resulted in a higher von Mises stress of (63.332 MPa) for the **BioHPP** system compared to (70.922 MPa) for the **Co-Cr** system, indicating effective shock absorption and distribution of forces during loading. The **Co-Cr** framework displayed higher stress concentrations in the bone, suggesting a potential for adverse effects.

Stress Concentration Patterns:

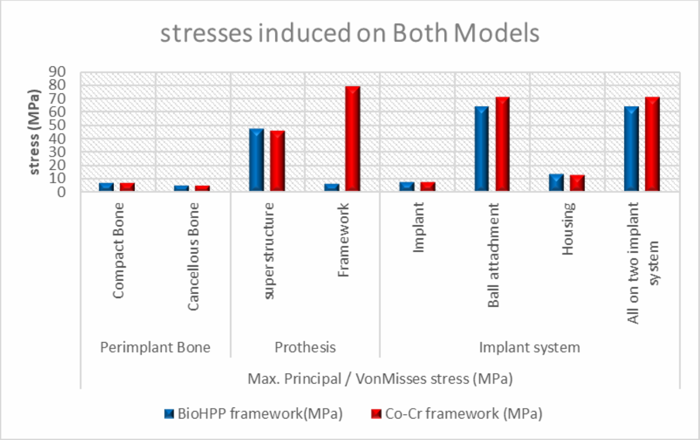
The **BioHPP** configuration exhibited lower maximum principal stress in both compact and cancellous bone compared to the **Co-Cr** framework, indicating greater potential for stress-related complications in the bone with the latter.

This comparative analysis highlighted the mechanical advantages of the All-on-Two ball attachment configurations with **BioHPP** over **Co-Cr** frameworks, particularly in achieving more efficient load distribution while minimizing stress on the surrounding bone and soft tissue structures.

Table 1: Comparison of Maximum principal stresses (MPa) and VM stress (MPa) induced by BioHPP & Co-Cr material on peri-implant bone, prosthesis and implant system using finite element analysis:



Structure	BioHPP framework (MPa)	Co-Cr framework (MPa)
Perimplant Bone (Maximum Principale Stress) (MPa)		
Compact Bone	7.3934	7.391
Cancellous Bone	5.59	5.5926
Prothesis (Vonmisses stress) (MPa)		
superstructure	47.191	45.725
Framework	6.706	78.547
Implant system (Vonmisses stress) (MPa)		
Implant	7.818	7.7998
Ball attachment	63.332	70.922
Housing	13.51	13.472
All on two implant system	63.332	70.922



IV. Discussion:

The rehabilitation of compromised ridges using two implant-retained overdentures has become the gold standard and offers good retention and stability along with an enhanced masticatory efficiency.(14) Conventional complete dentures may frequently fail to provide good retention, stability, clear speech, and masticatory efficiency. (15)

Since the mechanical properties of heat cured acrylic resin is not sufficient enough to maintain the longevity of the dentures, reinforcement in overdentures is often used to prevent fracture and deformation. (5) The purpose of reinforcement is not only to prevent fracture, but also to distribute the occlusal stress to the underlying denture bearing areas as uniformly as possible to minimize bone resorption. (9,16)

In the current study, two implants were positioned in the interforaminal space to improve biomechanical distribution in an implant-retained mandibular overdenture.(17) The flexion of an overdenture in this region is minimal due to the support provided by implants with ball attachments, which restrict tissue-ward movement and this in turn reduces stress on the underlying mucosa and the bone–implant interface.(18) These findings were in accordance with a study conducted by **Tokuhisa et al**.(19), which suggests that ball O ring attachments in comparison to bar attachments and magnet provide a better stress distribution and reduced movements of the denture.

In this study, the implant dimension chosen were 4.1 × 10 mm as it results in an increased implant stability(20) and a computer-guided stent was used to ensure accurate and perfect implant placement regarding implant angulation and point of insertion.(21,22)

A 150-N axial load was applied bilaterally and simultaneously on the first mandibular molar to simulate the mean value of posterior occlusal force in edentulous humans(23,24)

Fixed restraints were applied at the condylar zones of the mandible to prevent any displacement in these regions during loading. This setup was done to ensure accurate stress and force distribution throughout the implants, ball attachments, nylon rubber, and gingiva, allowing for a realistic simulation of the biomechanical behavior of the system.(25)

Von Mises stresses and maximum principal stresses were analyzed to provide a comprehensive evaluation of stress distribution. The von Mises stress was utilized to identify regions of potential mechanical fatigue or failure within the implants, prosthetic framework, nylon rubber ball attachments, and gingiva. Meanwhile, maximum principal stress was focused on assessing stress concentrations within the compact and cancellous bone. This analysis allowed us to identify regions susceptible to excessive stress that may influence bone health and stability.(26,27)

The results obtained from this study showed that higher concentrations of von Mises stress were observed in the BioHPP superstructure (47.191 MPa) with lower stress transfer on ball attachment (63.332 MPa) compared to the Co-Cr framework, which showed a stress of (45.725 MPa) for the superstructure and (70.922 MPa) for the ball attachment. This indicates that both configurations effectively anchored the prosthesis to the mandible, enhancing load distribution and reducing undesirable stress on surrounding mandibular structures. Furthermore, the BioHPP configuration demonstrated lower stress transfer to the ball attachment compared to Co-Cr, highlighting its potential for minimizing stress on attachment components.

Regarding Maximum Principal Stress, the analysis revealed that the BioHPP framework exhibited a more favorable distribution of maximum principal stress across the compact (7.3934 MPa) and cancellous bone (5.59 MPa) compared to the Co-Cr framework, which showed compact bone stress levels of (7.391 MPa) and cancellous bone stress levels of (5.5926 MPa). This suggests a lower risk of stress-related complications in the BioHPP configuration.

Regarding gingival interface, the presence of nylon rubber ball attachments resulted in a higher von Mises stress of (63.332 MPa) for the BioHPP system compared to (70.922 MPa) for the Co-Cr system, indicating effective shock absorption and distribution of forces during loading. The Co-Cr framework displayed higher stress concentrations in the bone, suggesting a potential for adverse effects.

V. Conclusion:

From biomechanical point of view, BioHPP frameworks exhibited more favorable outcomes than Co-Cr frameworks in implant supported overdentures.

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