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Finite Element Study on Short Implants Retaining Mandibular Overdentures with Different Denture Materials in Severely Resorbed Ridge

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Abstract

Aim: This study was conducted to evaluate stress distribution on short implants retaining mandibular overdentures with different denture materials by 3D finite element analysis.

Materials and Methods: One 3D finite element model was prepared simulating completely edentulous mandibular ridge. The overdentures were supported by four short implants of 6 mm length and 3.6 mm diameter. They were placed equally spaced along the mandible, with the lateral implants at least 5 mm anterior to the mental foramina.
Locator attachments and its caps and implant complexes were created on a commercial CAD/CAM package then imported into finite element software. The model was used to test PolyetheretherKeton (PEEK) and Polymethylmethacrylate (PMMA) as overdenture material under load of 100 N, that was applied on molars area, vertically and obliquely with an angle of 30 degrees.

Results: Under the proposed load, no failure can be expected in any component of the model, that Von Mises stress values were found under the acceptable physiological limits. However, PMMA overdenture deformed slightly smaller than PEEK one, as Von Mises stress difference was of order 3 to 6% less in PMMA overdenture under vertical loading, while this percentage jumped to 6 to 10% under oblique loading. On the other hand, flexible caps and short implants in case of PEEK overdenture, showed very low deformation and stresses values compared to PMMA ones under oblique loading.

Conclusion: Within limitations of this study, both tested materials (PEEK and PMMA) are suitable for usage in the studied case. Both materials showed low stress and deformation under vertical loading, while PMMA overdenture showed slightly better behavior. PEEK may provide superior behavior under oblique loading over the PMMA one.

Keywords: Short implants, Overdenture, Locator Attachment, PEEK, PMMA, Finite Element Method.

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Introduction:

Edentulous patients with severely atrophic mandibles may experience problems with conventional dentures that could be avoided by the construction of implant overdentures. Implant overdentures are considered a simple, successful, cost-effective and less invasive treatment option.[1, 2] However, the reduced amount of bone in severely resorbed mandibular ridges is challenging for implant placement as the bone volume is insufficient for implants placement with suitable dimensions, unless restoring the ridge by augmentation is performed. These techniques produce greater morbidity, longer times for treatment, and higher costs. Therefore, using short implants must be considered as a treatment alternative.[3] It has proven that more complications could occur in patients with severe bone loss when treated with vertical bone augmentation than in those treated with short dental implants. [4-6]

A clinical study by Arlin had reported the success rate may reach up to 94% for 6mm implants length after 2 years of loading.[6] Furthermore, Placement of three or four implants in the interforaminal area may

increase the implant-bone contact area that permits better stress distribution and decrease crestal bone loss.[7]

The biomechanical behavior of dental implant is directly related to its clinical survival rate since short implants exhibit lower bone/implant contact area, thus the loading concepts are considered one of the most critical factors influencing bone loss surrounding the implants. [8]

Various types of attachments have been suggested for implant-retained overdentures such as ball, O-ring, Locator, and bar attachments.[9] The Locator, which is self-aligning and has dual retention, is a popular type of un-splinted attachment. It is designed to provide accurate seating and secure adequate retention of implant-supported overdentures. Its resiliency, retention, and durability are favorable. [10,11] Since fractures of implants, attachments and prostheses can occur due to biomechanical stresses, so stress reduction in implant prostheses is very important to reduce the fracture rates. [12]

The material properties of the overdentures greatly influence the stress and strain distribution in the structure. The PMMA is the most popular polymeric material used for dentures fabrication. It was advantageous in low cost, ease of manipulation and good esthetic qualities. However, this material is not ideal in every respect. It has low flexural and impact strength and may cause allergies due to residual monomer. Therefore, some researchers have been interested in discovering materials that are similar to PMMA but have better properties. [13]

One of the most widely used materials nowadays is the PEEK, which is an important high-performance polymer that was introduced in the early 1980s by a group of scientists. PEEK has excellent strength properties, it is insoluble in common solvents, and has a high resistance to wear. It also expresses high biocompatibility invitro and invivo and doesn't cause toxic effects or inducing any inflammatory reaction, thus it is used successfully in producing fixed and removable prostheses. [14]

One of the main advantages of modified PEEK material is the high bond strength with PMMA or indirect composite materials [15]

A PMMA and composite primer (visio.link; Bredent GmbH &Co. KG) has been used successfully as a multi-layer veneers with different shades for PEEK framework. [16]

It has been proved that using perforated metal plates with complete dentures, strengthen the prostheses and reduce the fracture rates. [17] Thus according to this concept, for a patient suffering from an allergy to base metals, the use of high noble metal copings for retention of a PEEK overdenture framework could be used as a treatment modality which adds strength to the prosthesis and reduces the rate of fracture of PMMA resulting from stress concentration at areas of overdenture making contact with the abutments [18]

Thus, this study aimed to evaluate stress distribution on short implants retaining mandibular overdentures with two denture materials (PEEK and PMMA) by 3D finite element analysis

Materials and Methods:

A simplified model for mandibular bone and overdenture was created based on similar studies [19-21], where bone height was set to be 10 mm, and gingival height of 2mm. The four implants of 6 mm length and 3.6mm diameter (ASTRA TECH Implant System OsseoSpeed; Dentsply Sirona Implants, Mölndal, Sweden) were modeled and placed vertically in their exact position. Locator attachment, from the same manufacturer, was also modeled based on manufacturer data and placed on implants. All used materials were assumed to be isotropic, homogenous, linearly elastic and its properties are listed in **Table 1**.

The finite element models' components as the locator, caps, implant, overdenture, mucosa, cortical and cancellous bones were created on "Autodesk Inventor" Version 8 (Autodesk Inc., San Rafael, CA, USA) as presented in **Figure 1**. These components were exported as STEP files, to be assembled and meshed in ANSYS environment (ANSYS Inc., Canonsburg, PA, USA). The meshing software was ANSYS Workbench version 16. Mesh density was examined and optimized for accuracy and calculation time. The number of nodes and elements of each component were listed in **Table 2**, and screenshots for meshed components were presented in **Figure 2**.

The lowest area of the cortical bone was set to be fixed in place as a boundary condition, while unilaterally of 100 N was applied vertically and obliquely with an angle of 30 degrees at the central fossa of the first molar. Thus, four cases were analyzed for the two overdenture materials (PEEK and PMMA) under two loading conditions. Linear static analysis and solid modeling were performed on a personal computer Intel Core i7, processor 2.4 GHz, 6.0GB RAM. The model was verified against similar studies and showed good matched results. [19-21]

Material	Modulus of Elasticity [MPa]	Poisson's Ratio
Overdenture: PMMA	8,300	0.20
Overdenture: PEEK	5,100	0.40
Mucosa	680	0.45
Cortical	13,700	0.30
Cancellous	1,370	0.30
Implant complex (Titanium)	103,400	0.35
Nylon	2,400	0.39

Table 1: Materials properties

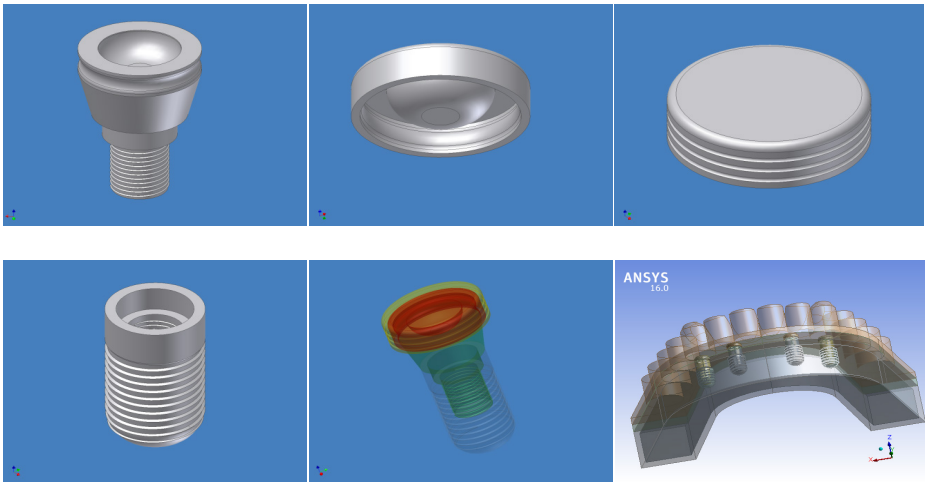

Figure1: Screen shots of the modeled components from Inventor screen, and model assembly from ANSYS screen

	Nodes	Elements
OD	182,482	122,811
Mucosa	10,801	1,776
Cortical	31,366	15,618
Cancellous	310,223	219,826
Implants	248,057	169,045
Locators	189,822	127,800
Ny Caps	88,774	59,410
Metal Caps	76,338	47,963

Table 2: Mesh density

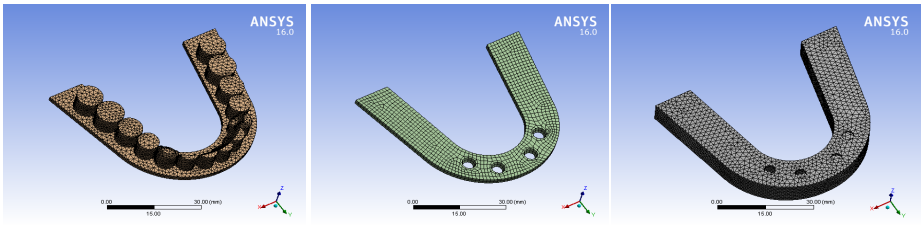

Figure 2: screen shots for sample of the meshed components

Results:

The results obtained from the four cases showed stresses within physiological limits, thus under the applied loads there is no possibility to find failure or cracks in any of the model components. **Figure 3** demonstrates screenshots from ANSYS containing total deformation and Von Mises stress distributions on some of the model components.

Stress and deformation distribution on all the model components did not change with changing overdenture material, while the values slightly changed. **Figures 4** and **5** compare extreme values of total deformation and Von Mises stress appeared on the mandible tissues and prosthesis respectively.

As presented in **Figure 4**, using less flexible overdenture material (PMMA) generate less deformation and stress on mucosa, cortical and spongy bone. Under vertical loading the total deformation was found of order 0.1 microns, which increased to be of order 0.3 microns under oblique loading. Similarly, Von Mises stress difference was of order 3 to 6% more for cases of using PEEK overdenture under vertical loading, while this percentage jumped to 6 to 10% under oblique loading.

Overdenture has a special behavior, that whatever the load direction, PEEK one deforms more than the acrylic overdenture, while PEEK one received less stress value. That may indicate changing loading mechanism during deformation under load.

Under oblique load the PEEK overdenture showed superior behavior, that implant complex and caps received less total deformation and Von Mises stress less than PMMA one by about 15 to 20%.

Vertical load showed very small values with similar behavior with both materials in comparison to oblique loading. That total deformation difference did not exceed 6% and Von Mises stress difference may reach 25%.

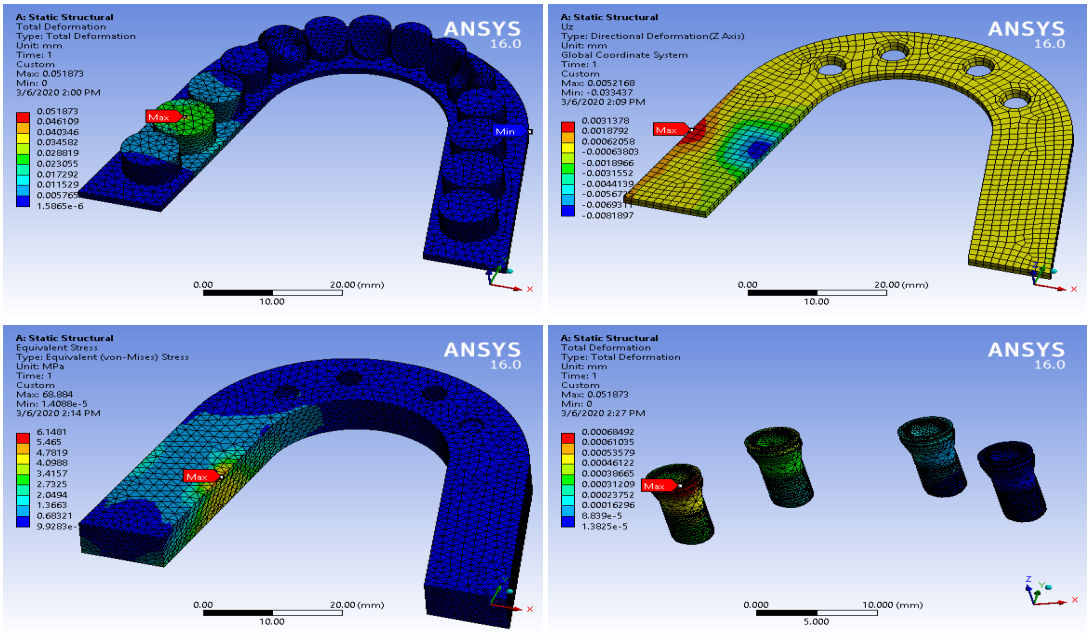

Figure 3: Sample of total deformation and Von Mises stress distributions

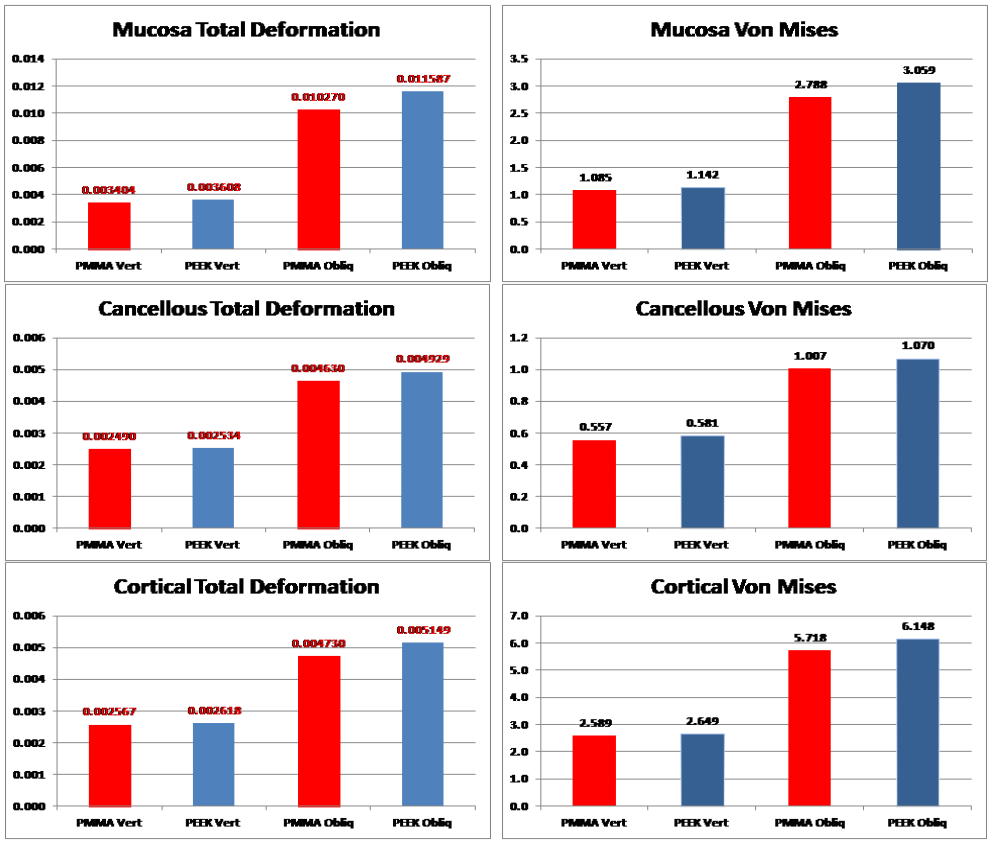

Figure 4: Mandible tissues results comparisons

Figure 5: Prosthesis results comparison

Discussions:

Management of biomechanical stresses is very important in implant prostheses to reduce the fractures rates of implants, attachments and prostheses [12]

The results obtained from this study showed stresses within physiological limits, thus under the applied loads there was no possibility to find failure or cracks in any of the model components. This finding could be attributed to the use of four implants to support the overdenture that distributes the load more evenly. Together with the use of resilient, low profile, locator attachment as whenever the attachment system is resilient, stresses in the peri- implant bone is reduced as part of these stresses is directed to the posterior ridge resulting in better stress distribution and minimize the total stress level. This finding is following the results obtained by Gulje *et al* 2012 and Edadian *et al* 2015 [22, 23]

This finite element study demonstrated a slightly higher stress values were recorded when oblique 100N load was applied. This result seemed to be in one line with those published by Abdelhamid *et al* 2015. Therefore, the forces should be directed along the long axis of the overdenture teeth for better stress distribution and favorable implant prognosis. This can be achieved by carefully designing the occlusion to reduce the lateral forces. [24,25]

Upon comparing the two tested denture base materials, we found that Stress and deformation distribution on all the model components did not change with changing overdenture material. However, the less flexible overdenture material (PMMA) generate less deformation and stresses on the mucosa, cortical and spongy bone than the PEEK one, under vertical and oblique loading. That is because PMMA as a material can resist more load before resting on mucosa and transmitting stresses to the supporting structures. This finding is in agreement with other studies that concluded that in multiple implant-supported superstructures, the spread of the implants and stiffness of the superstructure will reduce the resultant stress. [26]

On the other hand, the more elastic denture base PEEK under oblique loading showed superior behavior, that implant complex and caps received less total deformation and Von Mises stress than PMMA one by about 15 to 20%. This could be attributed to its higher modulus of elasticity (around 4 GPa) that allows gentle transmitting of the chewing pressure and decreasing the risk of implant fracture. In addition, as it decreases the nylon cap deformation, the life time of it will be prolonged. [27]

Conclusions:

Within the limitations of this in-vitro study it may be concluded that short implants can be considered as a good alternative implant therapy to support overdentures in severely resorbed mandibles. Both tested overdenture materials (PEEK and PMMA) are suitable for usage in the studied case as they showed low stress and deformation under vertical and oblique loading. However, PMMA overdenture showed slightly better behavior as it distributes the applied load in a better manner that reduces stresses on the underneath structures.

On the other hand, PEEK may provide superior behavior on the implant complex and caps under oblique loading that reduces the risk of implant fracture and prolongs the lifetime of the nylon cap.

ETHICAL APPROVAL:

This research didn't require ethical approval and followed the Helsinki declaration.
The authors declare that they have no conflict of interest.

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