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Stress distribution & Deflection in an Armany's class II Obturator cast partial framework design fabricated with Titanium, PEEK and cobalt chromium alloy- A 3D FEA study

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Abstract

Aim and Objectives: To find out stress distribution and deflection on Armany's class II obturator cast partial denture framework fabricated with 3 different materials.

Objective: To determine which material is more suitable for fabrication of obturator prosthesis.

Which material Comfortable for patients.

Material and Methods: Three- dimensional finite element model of an Armany's class II obturator along with cast partial denture framework was reconstructed to carry out the analysis. For fabrication of CPD 3 different material was taken, titanium alloy (grade IV), cobalt-chromium alloy and PEEK. 120 N loads in horizontal & vertical direction wad applied.

Statistical Analysis Used: The results of the simulations obtained were evaluated in terms of Von Mises equivalent stress levels at the assembly level (bone and tooth framework)

Results: The stress distribution & deflection executed by ANSYS software provided results that enabled the tracing of Von Mises stress and deflection field in the form of color veiled bands with standards in Mega Pascal (MPa).

Conclusion: The study shows that Von Mises stresses are higher for the frame work fabricated with cobalt chromium alloy compared to Titanium alloy compared to PEEK material. The framework made of PEEK material showed more deflection than titanium alloy and least deflection were seen in cobalt chromium alloy.

Keywords: Finite element analysis, Armany's class II, PEEK, titanium alloy, cobalt-chromium alloy, Von Mises stresses.

Introduction

Quality of life is an important consideration in philosophy, medicine, religion and economics to every individual. Patient present with malignancy mostly necessitates surgical removal of a major portion of the palate with ablative surgery & their management. The resultant palatal defect after surgery could be small or massive (when involves removal of a major portion of the palate, maxillary sinus, and/or nasal cavity). The patient's quality of life often collapses following the surgical resection of the tumor mass because of the exploitation of function, speech, and aesthetics. [1] To overcomes the functional and psychological impact of the surgery, a surgical microvascular and/or prosthetic reconstruction must be carried out to improve the patient quality of life [2, 3.] Surgical rehabilitation of maxillary defects is not always possible due to the lack of donor sites, size of the defect, general health of the patient, and the risk of morbidity[4.]

Maxillofacial prostheses (MFPs) are considered a cost-effective treatment option to reconstruct the lost dentition and missing structures in patients suffering from major maxillary defects[5,6.]

Even though many classifications have been introduced to distinguish the maxillary defect[7-10]. Armany's classification was the most one followed by researchers due to its simplicity and smoothly communication among the maxillofacial prosthodontists[11.]

Obturator prostheses are considered to be the preferred choice for the restoration of acquired maxillary defects. Extensive invasion of maxillary bone has an obliterated impact on the biomechanics of an obturator. Effect of leverage and weight of the prostheses aggravates the stresses on the supporting tissues during function. Henceforth the, evaluation of the configuration, extent of the invaded maxillary lesion and the preserved teeth are key to the success of the prostheses.

Armany's class II defect is a solitary, unilateral defect swamping premaxilla. Arch is simile to a Kennedy class II condition, where bilateral or tripodal strategy is preferred. Surgeons must be intimated for the improved prosthetic rehabilitation in a class II situation by planned surgery and complete removal of metastasis. Hence, one of the most commonly seen acquired defects of the maxilla involves the resection of the dentition and the alveolar bone involving the tumor site explicitly Armany's class II defect.[12]

The finite element analysis (FEA) is an upcoming and significant research tool for biomechanical analysis in biological research. It is an ultimate method for modeling complex structures and analyzing their mechanical properties. Finite element assesses multifactorial field variables such as stress distribution, hydraulics of the field and deflective nature and simulates a real time situation at points which are connected by strings. It mimics a spider web, so that a minimal change in a local region is transmitted throughout the structure with a suitable gradation of consistency and precision. It enables to re-experiment many times, it can be performed on a computer software without putting any stress on the patient's body from technical materials, which is specifically difficult for patients who have undergone surgery for removal of tumour. The results derived can be displayed in visual simplicity.

There are varieties of materials available which are used for fabrication of cast partial denture framework with obturator prosthesis. Cr-Co alloy has remained the designated metal for partial denture prostheses but the usage of commercially pure titanium and Ti alloys for dental applications has amplified progressively since report of its application in 1977. Titanium is the most bio-compatible metal used for restorations and is also less rigid than cobalt chromium alloy, whose hardness is of concern, as it is harder than the tooth enamel, which can cause in vivo wear. The flexibility of titanium alloys has increased its usage in removable prosthodontics compared to cobalt-chromium alloys.[12] Now a days one more material is being extensively used in field of dentistry for the purpose of rehabilitation of defect part, that new material is- polyether ether ketone (PEEK). PEEK (-C6H4-OC6H4-O-C6H4-CO-) n is a semicrystalline linear polycyclic aromatic polymer. PEEK is white, radiolucent, rigid material with great thermal stability up to 335.8° C. It is non-allergic and has low plaque affinity. Flexural modulus of PEEK is 140-170 MPa, density – 1300 kg/m3 and thermal conductivity 0.29 W/mK. PEEK's mechanical properties do not change during sterilization process, using steam, gamma and ethylene oxide. Young’s (elastic) modulus of PEEK is 3-4 GPa. Young’s modulus and tensile properties are close to human bone, enamel and dentin. Polyether ether ketone is resistant to hydrolysis, non-toxic and has one of the best biocompatibilities. Special chemical structure of PEEK exhibits stable chemical and physical properties.[13-14]

The understanding of the distribution of the stresses and the deflection of the obturator can be observed with the help of Finite Element Analysis which is a gold standard research tool. Three-dimensional FE analysis can be utilized to verify displacement pattern and deformation area with repetition, without designating any stress on the human body from technical materials, which is especially difficult for patients who have undergone surgery for removal of tumor. The results derived can be displayed visually in a very simple manner, because of its improved simplicity and reproducibility. Finite element analysis has gained acceptance for stress analysis and deflection.[13] A three-dimensional Finite Element model with framework for an Armany’s class II obturator was designed to evaluate the stress and deflection pattern in the frameworks proficient of Cr-Co alloy and Ti alloy & PEEK material.

Materials and Methods

The Study was categorized as: Geometrical representation of model, meshing of model, setting of material properties, application of different load, analysis of stress pattern, & analysis of deflection patterns.

Model generation

Geometrical representation of model

Modelling of the dentate maxilla with the Armany’s class II defect

The algorithm in this study is to generate finite element models from computerized tomography scan (CT scan) data of a dentulous maxilla. Contouring of data profiles were transformed into the x, y and z axis points and read by finite element program which connects these axis points forming a line geometry known as wire frame modelling. These inter connecting lines are known as surface modelling. Joined adjacent profiles created three dimensional volumes which defined the final solid geometry of the defect. By undergoing this process 3D model of maxilla with Aramany’s class II defect was created.

Modelling of the obturator framework

For the study an obturator model was manually drawn and the removable partial denture framework were designed. The design included a tripodal obturator design with complete plate as the major connector. Indirect retainer was planned on the right first premolar, and direct retention was provided by the I-bar clasp placed on the right first premolar, and embrasure circumferential clasp on the right first and second molar. Rest seat preparations on 14, 16, 17, and 24 were carried out to receive rest of the cast metal framework following the principle of Armany's Class II obturator design.

Setting of materials properties

The corresponding elastic properties such as young's modulus (E) and poisons ratio () of the bone, dentition on the non-defect side, cobalt chromium alloy, titanium alloy, PEEK material, acrylic resin was determined by literature survey. The geometric model was impregnated with materialistic properties. (Table no.1)

Load and constraints

In this study, the load was applied into two directions, 120N vertical load was transferred in the occluso-gingival path on the teeth region of the prosthesis and 120N horizontal load was applied on the bucco-lingual path on the region of the prosthesis.

Meshing and contact characteristics

Hyper mesh 11 was utilized in constructing the models. Utmost care was taken to concentrate elements in the region of greatest interest of stress distribution & deflection pattern. The completed geometric anatomical model was formed of total number of 117701 nodes and 78825 elements.

Analysis of stress pattern

A 120N vertical & horizontal emulating masticatory forces were applied to model. Scrutiny of the model was done with ANSYS version 14.5 by means of Von Mises stress analysis. The stress is concentrated within the metallic framework of the prostheses.

Analysis of deflection pattern

Areas of deflection in the model was evaluated using the vector deflection analysis.

Results

In the present study, the forces were applied in two directions in each model & Von Mises stress was calculated.

It was observed that the highest amount of stress or the maximum stress of 700.624 MPa was seen in the Assembly (bone+ framework) fabricated with cobalt chromium alloy on application of the vertical load of 120N which is considerably more than maximum stress of 700.549 MPa seen with the Assembly (bone+ framework) fabricated with titanium alloy and similarly more than maximum stress 698.945 was seen with the Assembly (bone+ framework) fabricated with PEEK. (Table 2) (Graph 1)

It was observed that there had been differences in the stress at the natural teeth and the contra lateral side.

Deflection pattern between the obturator prosthesis fabricated with cobalt chromium alloy, titanium alloy and PEEK. It was observed that the highest maximum deflection value of 0.271828mm was seen with PEEK followed by cobalt chromium 0.220703mm and the least deflection was seen with titanium alloy with 0.227508mm when the 120N was applied. (Graph-2)

Discussion

The degree of intricacy in Finite element analysis is resolute by the number, type of finite elements, physical and the mechanical behavior. Most of the analyses have treated the materials as having linear elastic properties, in which the structural deformation is reliably proportional to the engaged forces. Several dental studies utilizing finite element methodology have been seeing biological tissues with isotropic properties. In the studies done by Miyashita et al. (2012), Gao et al. (2006), Zhao et al. (2008); the process of finite element analysis commenced with the creation of CAD model from the CT scans of the selected biological structures, in addition a simplified tooth model without periodontal ligament was used to simplify the analysis of the result and the equivalent method has been followed in this current study. Finite element has been used in removable prosthodontic field with very limited studies about the obturator prostheses. Clinically the location, size & extent of the surgical resection site and the patient's oral hygiene status directors the prosthetic planning for obturator prostheses. Evaluating the stress distribution of the Armany's Class II prosthesis on the maxilla provides an understanding with biomechanics of the prosthesis, and preserving the anatomical structures. Finite element analysis makes distinguishing the material properties of the supporting structures and boundary (Hase et al., 2014). Although the masticatory force varies for each individual and each food, a value previously established in a report that investigated occlusal force in partially edentulous patients with maxillary lesions where the magnitude and the direction of the loading forces were derived from the studies of Eto et al and Wedel et al.

Followed by

Stress distribution

In this study 120N load was applied in two different directions and the stresses within the assembly of each material, which includes bone. Framework & natural teeth were individually analysed. It was observed that the maximum stress was seen in the assembly fabricated with cobalt chromium alloy which was in accordance with study done by Miyashita et al and the supreme stress was seen when the incisor was subjected to the vertical load. In comparison the assembly of PPEK material showed minimum of stress distribution followed by titanium alloy which is a gold stranded material it also shoed least distribution, but not less than PEEK. The stress distribution for assembly (bone+ framework) is irrespective of the focused area and the path of the determined load.

In addition, the stress on the remaining natural teeth on the contra-lateral side was also seen especially in the pre-molar region. In the present study, the stress distribution was seen with all the three assembly, the highest stress was seen in cobalt chromium alloy followed by PEEK least with titanium alloy assembly. From this, it can be attributed that the hardness of cobalt chromium which is more than PEEK and titanium alloy. It was rational in this research that regardless of the path and area of the applied force the maximum stress concentration was seen in the premolar area of contra-lateral side of alloys studied. In three of the cases the stress was concentrated in cervical half and apical half of root region, when vertical and horizontal load was applied.

Deflection pattern

In this study the deflection pattern is interpreted in millimeters. The difference between the deflection seen in the frameworks fabricated with cobalt chromium alloy and the titanium alloy was seen to be negligible. with the titanium alloy framework showing slightly higher values of deflection than the cobalt chromium framework. But the maximum deflection was seen with PEEK. It is more than titanium and cobalt chromium. This result may be attributed to the greater flexibility exhibited by the PPEK, titanium alloy when compared to the cobalt chromium alloy (Bridgeman et al., 1997). The deflection was perceived to be in the direction of the applied load. This study the deflection of cobalt chromium and titanium were almost equal, out of which with maximum precision PEEK material having deflection maximum.

Limitation of the study

- All the vital tissues in this study were isotropic instead of anisotropic.

- The loads that were applied were static load which is different from the dynamic load encountered during function.
- In this study lone type of acquired maxillary defect was considered (Aramany class II) and the stress within the framework and natural teeth were taken into consideration.
- Some simplification such as not including periodontal ligament.

Conclusion

Maximum stresses were located within the cobalt chromium alloy framework irrespective of the concentrated area and determined force applied. Stresses were perceived to be maximum on the application of the horizontal load on the prostheses and the stress was concentrated on the proximal plate area. The deflection values which were interpreted in millimeters was seen to be almost similar in both the frameworks but the PEEK framework showed a higher overall deflection.

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Legend Figure and Table

Table 1: Mechanical properties of tissues and material associated with finite element analysis

Materials/ Structures	Young Modulus (GPa)	Poisson Ratio
Cortical bone	13.7	0.30
Cancellous bone	1.37	0.30
Periodontal ligament	0.069	0.45
Dentin	18.6	0.31
Palatal mucosa	0.68	0.45
Acrylic resin	2.83	0.45
Cobalt-	149	0.35
chromium alloy	110	0.33
Titanium alloy	3.4*	0.4*
PEEK		

*Values provided by manufacturer.

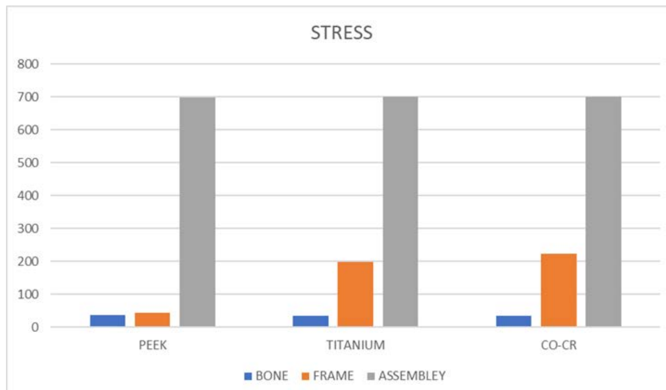
Model is assigned respective values from the studies done by Miyashita et al & Akay et al.

*Young's modulus (E) measured in Giga Pascal (GPa).

Table 2: Stress distribution and deflection analysis of different framework design material.

		STRESS DISTRIBUTION			DEFLECTION	
	BONE	FRAME	ASSEMBLY	BONE	FRAME	ASSEMBLY
PEEK	37.0642	42.7933	698.945	0.170305	0.271828	0.271828
TITANIUM	34.2237	197.69	700.549	0.148382	0.227508	0.227508
Co-Cr	33.6491	221.818	700.624	0.145071	0.220703	0.220703

Graph 1: Comparison of stress distribution analysis of different material framework



Graph 2: Comparison of deflection analysis of different material framework

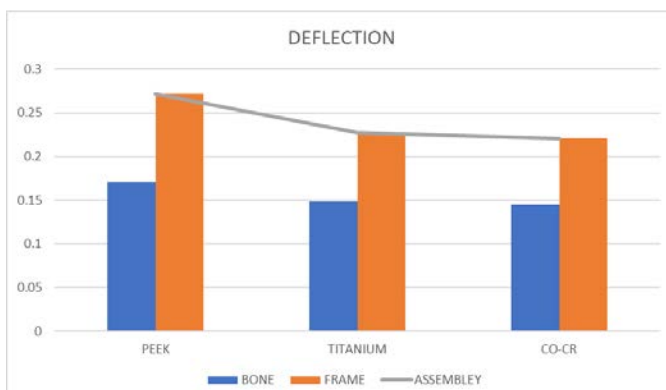


Figure 1: Stress Distribution of Co-Cr Assembly (bone+ framework) on application on vertical load & horizontal load, *Figures depicting various color coding in the framework area. *Inky blue expresses the least stress whereas red shows the maximum stress in the area.

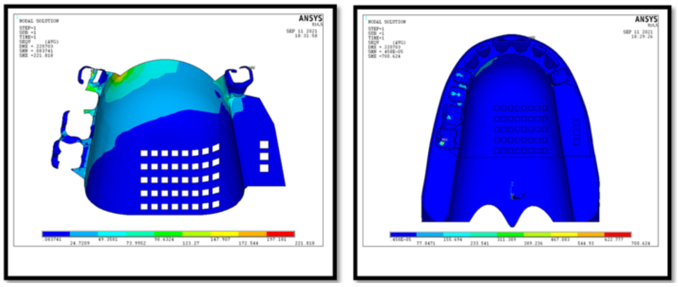


Figure 2: Stress Distribution of Titanium Assembly (bone+ framework) on application on vertical load & horizontal load, Figures depicting various color coding in the framework area. *Inky blue expresses the least stress whereas red shows the maximum stress in the area.

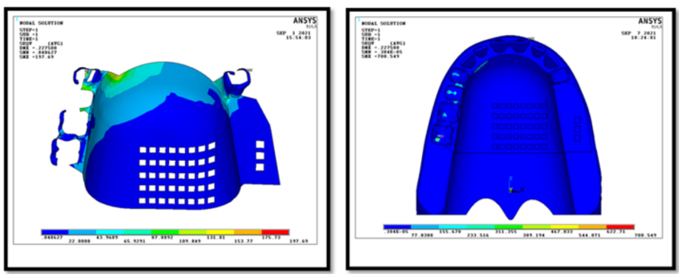


Figure 3: Stress Distribution of PEEK Assembly (bone+ framework) on application on vertical load & horizontal load Figures depicting various color coding in the framework area. *Inky blue expresses the least stress whereas red shows the maximum stress in the area.

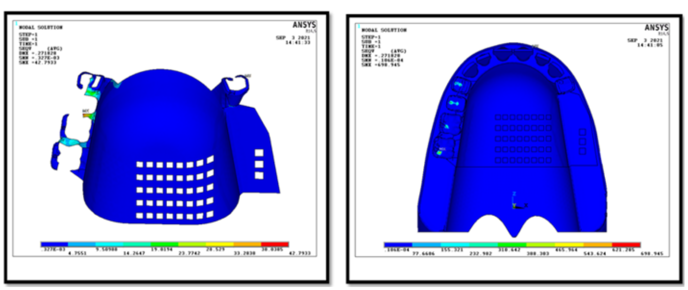


Figure 4: Deflection pattern of PEEK*Figures depicting various color coding on the prostheses area. *Red depicting the maximum stress on the teeth area.

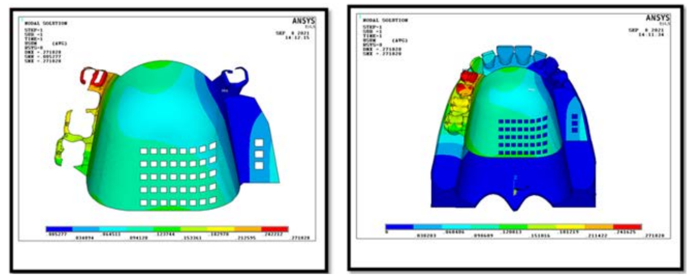


Figure 5: Deflection Pattern of Titanium, *Figures depicting various color coding on the prostheses area. *Red depicting the maximum stress on the teeth area.

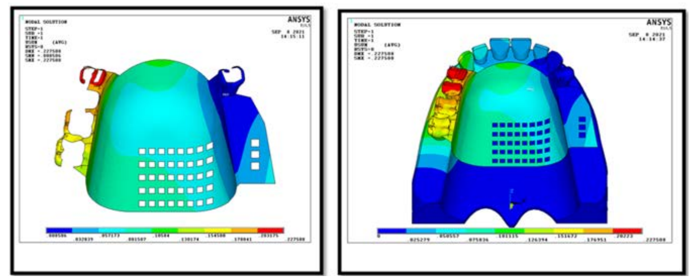


Figure 6: Deflection pattern of cobalt chromium, *Figures depicting various color coding on the prostheses area. *Red depicting the maximum stress on the teeth area.