

## BIOMECHANICS OF POLY ETHER ETHER KETONE VERSUS NYLON AS AN ATTACHMENT MATERIAL IN MANDIBULAR KENNEDY CLASS II REMOVABLE PARTIAL DENTURES. (3D-FINITE ELEMENT ANALYSIS STUDY)

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### ABSTRACT

**Purpose:** This study aimed to compare the biomechanical behavior of PEEK and Nylon in unmodified Kennedy class II restored with unilateral, tooth/implant-supported prosthesis using a three-dimensional finite element analysis (3D-FEA).

**Materials and methods:** A 3D-FEA model of mandibular unmodified Kennedy class II restored with unilateral, tooth/implant-supported and attachment-retained prosthesis. Premolars on the edentulous side were splinted and restored with porcelain fused to metal crowns with an OT-attachment mounted their distal surface and a distal titanium implant with a ball abutment in the 2<sup>nd</sup> molar region. Anterior and posterior retentive caps were modelled twice with (PEEK and Nylon). Oblique and vertical load was applied on each type of retentive caps. Von Misses stresses in the peri-implant bone, implants, OT-attachments and OT-connectors, ball abutments and prosthesis of each model was calculated. The numeric data were then collected, color-coded, and compared between the models.

**Results:** The highest stress concentration was in horizontal unsupported bar of OT-attachment followed by OT-connector at the junction of OT- attachment with splinted crowns in both Nylon and PEEK models under oblique load. Minimal stresses were in the peri-implant bone and implants in both models under both vertical and oblique load.

**Conclusions:** PEEK can be a valid alternative option to nylon for rehabilitation of unmodified Kennedy Class II cases with unilateral tooth/implant- supported prosthesis retained with double ball attachments. The design simulated in this study should be modified before it can be recommended for clinical use to improve occlusal support and minimize the stresses transmitted to OT-attachment and OT-connector.

**KEY WORDS:** OT-attachment, Kennedy Class II, Tooth/Implant-Supported Prosthesis, PEEK Retentive caps, Nylon Retentive Caps, 3D-FEA.

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## INTRODUCTION

Combined tooth/ implant-supported removable prostheses have been successfully used for the rehabilitation of Kennedy Class I and class II partially edentulous patients.<sup>1</sup> Such a prosthetic design provides the patients with a low-cost alternative treatment to fixed implant-supported prostheses.<sup>2</sup> Implant placement at the distal edentulous ridge alter the clinical situation from Kennedy class I or class II tooth-and-mucosa supported to Class III tooth-implant-supported cases. Distal implant placement minimizes the distal base displacement with anticipated reduction in distal bone resorption and prosthodontic maintenance required.<sup>3-5</sup> Disparity of support is no longer an issue, with optimal load distribution between implant/bone interface and basal seat bone. Among the other factors that influence the biomechanical situation in Class III tooth-implant supported prostheses is the proper selection of the attachment system used.<sup>6</sup> Attachment system selected should allow optimal biomechanical load distribution to compensate for difference in the movement between tooth/implant complex. Natural teeth abutments with sound periodontal ligament exhibit increased physiological mobility compared to rigidly anchored osseointegrated implants. Osseointegrated implants undergo less than 10  $\mu\text{m}$  of displacement opposed to 15-20  $\mu\text{m}$  in axial direction and 150-200  $\mu\text{m}$  in the horizontal direction for abutment teeth.<sup>7</sup> The difference in the magnitude between tooth-implant movements creates a cantilever and increased load on implant, and peri-implant bone and possible torque and intrusion force on natural abutment.<sup>8,9</sup> Thus, the attachment selection is of prime importance for successful long-term treatment prognosis.<sup>8</sup>

Recent developments in the field of Biomaterials have led to the introduction of various novel materials that can be used for the fabrication of different attachment systems. Polyether ether ketone (PEEK) represents a modification of the thermoplastic high-

performance polymer group polyether aryl ketone (PEAK). PEEK is a biocompatible, high-temperature thermoplastic polymer with adequate mechanical properties, a melting point of about 343°C, a density of 1.3 to 1.5 g/cm<sup>3</sup>, and an elastic modulus between 3 and 4 GPa.<sup>10</sup> PEEK has been used as an alternative retentive cap material to conventional nylon caps in implant overdenture cases with demonstrated reduced wear properties, increased retention, patients' satisfaction and suggested decrease in needed maintenance events.<sup>11-14</sup> However, up to date and according to authors' knowledge there has been no evaluation of either biomechanical or clinical behavior of PEEK as retentive cap material in cases of partially edentulous cases particularly those of unilateral, tooth/implant-supported removable prosthesis in Kennedy class I and II cases.

One of the treatment alternatives for the management of unmodified Kennedy class II cases is unilateral implant-assisted, removable prostheses with extracoronal attachment mounted on the anterior abutment to avoid unsightly clasp appearance, and to improve the esthetic outcome and as well increase the patients' acceptance of treatment.<sup>15-17</sup> Several in vitro studies have investigated the biomechanical behavior of implant supported removable partial dentures in terms of rigid versus resilient implant attachments, mesial and distal implant placement and the use of different attachment systems.<sup>5,18-22</sup> Nevertheless, the influence of the retentive cap material has not been investigated.

Therefore, the aim of this study was to evaluate and compare the biomechanical behavior of PEEK and Nylon retentive caps in cases of unmodified Kennedy class II cases restored with unilateral, tooth/implant-supported prosthesis retained anteriorly with extracoronal OT-attachment and posteriorly with ball attachment using a three-dimensional finite element analysis (3D-FEA).

The null hypothesis assumed that there would be no difference in biomechanical behavior between

PEEK and nylon retentive inserts when used in cases of unmodified Kennedy class II cases restored with tooth/implant-supported unilateral removable prosthesis.

## MATERIALS AND METHODS

### Model design

A 3D-FEA model of partially edentulous mandible representing unmodified, Kennedy class II case restored with an attachment-retained, tooth/implant-supported prosthesis was simulated. Premolars on the edentulous side were splinted and restored with porcelain fused to metal crowns and an OT-attachment was mounted on the distal surface of the crown restoring second premolar. A space of 1mm was left between the horizontal arm of the female part of OT attachment and underlying mucosa to provide a self-cleansing design.

A distal titanium implant (4.1mm in diameter and 10 mm in length) with a ball abutment (4mm in diameter) was inserted in the 2<sup>nd</sup> molar region. On top of this assembly, a unilateral implant supported prosthesis was designed which was attached anteriorly with retentive caps on OT ball attachment and posteriorly on implant ball abutment. Anterior and posterior retentive caps were modelled twice with two different material properties.

Once retentive PEEK caps were simulated and in the second simulation Nylon caps were modelled. Oblique and vertical load was applied on each type of retentive caps resulting in four simulation models; Peek and Nylon retentive caps with vertical and oblique load application. The mandibular bone was modelled into D2 bone type as per Zarb and Lekholm classification.<sup>23</sup>

Initially, the 3D-model of each component was created and finally all the components were assembled together. Mandibular model featuring cortical and cancellous bone was created using Mimics Medical 21.0 and Materialise 3-Matic

Medical 13.0 (Mimics Innovation Suite, Leuven-Belgium) by segmentation from DICOM file of a patient's CBCT. Patient's informed consent was obtained for the use of his CBCT for the purpose of this study. For modelling of cortical bone, DICOM file was opened in Mimics Medical 21.0, and a cortical mask was created by raising the threshold of Hounsfield unit (HU) to 600 HU to mark cortical bone only as it exhibits higher density than that of the cancellous bone and soft tissue. Similarly, modelling and segmentation of the cancellous bone was done with same technique. HU threshold levels were changed, lowering the minimum HU level to 12 HU and the maximum HU level to 649 HU. Segmented part was calculated to create optimal quality 3D cancellous bone model. Finally, the 3D cortical and cancellous bone models were saved as STL files for later use. Similarly, STL files of the teeth, roots and periodontal ligaments were created and saved for later use.

Software Solidworks (SOLIDWORKS 2020; Dassault Systèmes SOLIDWORKS Corp) was used to generate the CAD model of both implant (Legacy 4) and ball abutment (Cowellmedi Co., Ltd. Egypt) according to the dimensions provided by the manufacturer. To assemble the implant model into bone models, cortical, cancellous bone and gingiva models were imported to Materialise 3-matic Medical 13.0 (Mimics Innovation Suite, Leuven-Belgium) followed by the implant model. Interactive translation and interactive rotation features were used to align the implant model within the bone models. Modeling of the nylon and PEEK caps was also performed on Solidworks detailed engineering feature and was aided freehand using product description of some of the commercially available products with some modifications to produce the desired dimensions for this study.

The OT-attachment superstructure and splinted crown models were created on Exocad Dental DB 2.2 Valletta (Smart optics Sensortechnik GmbH

Inc., Bochum, Germany). Finish line was detected and manually adjusted on the prepared abutment teeth followed by editing the crown bottoms including gap layer, and borders. A cement layer of 0.2 mm thickness was also created. The crowns were then added and its orientation was adjusted in 3D directions (occluso-gingival, mesio-distal and bucco-lingual directions) resulting in well-aligned crowns.

The simulated models were then imported to Geomagic Design X (Artic 3D, Luxembourg) software to convert them into solid parts and allow their superimposition for Boolean subtraction to obtain 3D-CAD of the final model and the resultant file was exported as parasolid extension file to ANSYS program as a function area to allow for finite element analysis.

### Elements and Nodes

The models were meshed with a parabolic tetrahedral element in the current FEA model simulation. The number of elements and nodes in each model are presented in **Table 1**.

### Material properties

Mandibular bone and other materials simulated in the study were assumed to be homogenous, isotropic and linearly elastic. **Table 2** shows the properties assigned to each material used in the simulation.

### Boundary condition

All the components were assumed to have a fixed bond at the interface with the contacting structures, except for nylon or PEEK retentive caps with ball abutment and OT-retentive ball attachment, and the fitting surface of denture/mucosa interfaces where a no-penetration-slip contact was simulated. The teeth were also assumed to have no-penetration-slip contact with periodontal ligament. For the implant/abutment interface, metallic housing with OT

retentive cap, the implant crown and the retentive cap interface, the crown with retentive cap and ball abutment interface a frictional (adjust to touch) contact was assumed. The implants were assumed to be completely and successfully osseointegrated with a 100% bone-implant contact.

### Constraints and loads

Load of 75 N per premolar, 75 N for 1<sup>st</sup> molar and 100 N for 2<sup>nd</sup> molar was applied vertically and obliquely to fossae of artificial teeth and lingual inclines of buccal cusps respectively. The numeric data were then collected, color-coded and compared between the models. Constraints were applied at inferior border of mandible in the region of insertion of masseter muscle, coronoid process in the region of insertion of medial and lateral pterygoid muscles, and posteriorly at the back of mandibular model to fix entire assembly in position during load application. Therefore, a boundary condition (zero displacement) was applied on the bottom nodes of the former regions in the (X, Y and Z) directions.

Mechanical static structural ANSYS 19.2 software (ANSYS 19.2; Swanson Analysis Systems Inc.) was used to compute the maximum equivalent stresses (Von Mises stresses) in the peri-implant bone, implants, OT- attachments and OT- connectors, ball abutments and in tooth/implant supported prosthesis of each model. The numeric data were then collected, color-coded, and compared between the models.

### RESULTS

Generally, the highest stress concentration was recorded in OT-attachment followed by OT connector at the junction of OT- attachment with splinted crowns in both Nylon and PEEK models under oblique load followed by vertical load. Minimal stresses were recorded in the peri-implant bone and implants in both models under both vertical and oblique load.

**Stress Distribution in implants and peri-implant bone**

Comparable von Mises stress values were found in the peri-implant bone and in implants in Nylon and PEEK models under both vertical and oblique load application (Table 3). *Under vertical load*, the highest von Mises stresses in the implants were concentrated at the top of ball abutment and at the neck of the ball abutment in PEEK and Nylon models respectively (Fig.1 & Table 3).

In case of peri-implant bone, under the vertical load the highest von Mises stresses were concentrated at the middle third of peri-implant bone at almost the level of sixth implant thread in both models (Fig. 1 & Table 3). *Under the oblique load*, there was more apical spread of stresses in both models and the highest stresses were concentrated at the level of apical third of peri-implant bone implant (Fig. 1 & Table 3).

TABLE (1) The number of elements and nodes in each model

Name	Vertical load peek	Vertical load nylon	Oblique load peek	Oblique load nylon
Nodes	1154346	1154451	1154124	1154481
Elements	703395	703547	703154	703157

TABLE (2) Material properties used for simulation

Materials	Components	Elastic Modulus (MPa)	Poisson's ratio
Cortical bone	Mandible	13,700	0.3
Trabecular bone	Mandible	7,930	0.3
Titanium	Implants Ball abutment	110,000	0.33
Acrylic	Partial overdenture	2770	0.3
Nylon	Nylon Caps	2700	0.45
PEEK	PEEK Caps	3600	0.39
Cr-Co	OT attachment	210,000	0.29
Porcelain fused to metal	Splinted crowns on premolars	70,000	0.19
Resin Cement		8300	0.35
Periodontal ligament		0.68	0.49
Mucosal tissue		200	0.15

TABLE (3) Maximum von Mises stresses in different components of PEEK and Nylon models under both vertical and oblique load

Name	Vertical load PEEK	Vertical load Nylon	Oblique load PEEK	Oblique load Nylon
OT attachment	129.19	212.49	360.62	363.13
OT attachment connectors	89.203	133.41	201.76	186.07
Crown	50.098	162.58	78.927	78.885
Implant	51.246	48.25	42.991	42.876
Peri-implant bone	16.185	16.181	19.137	19.113



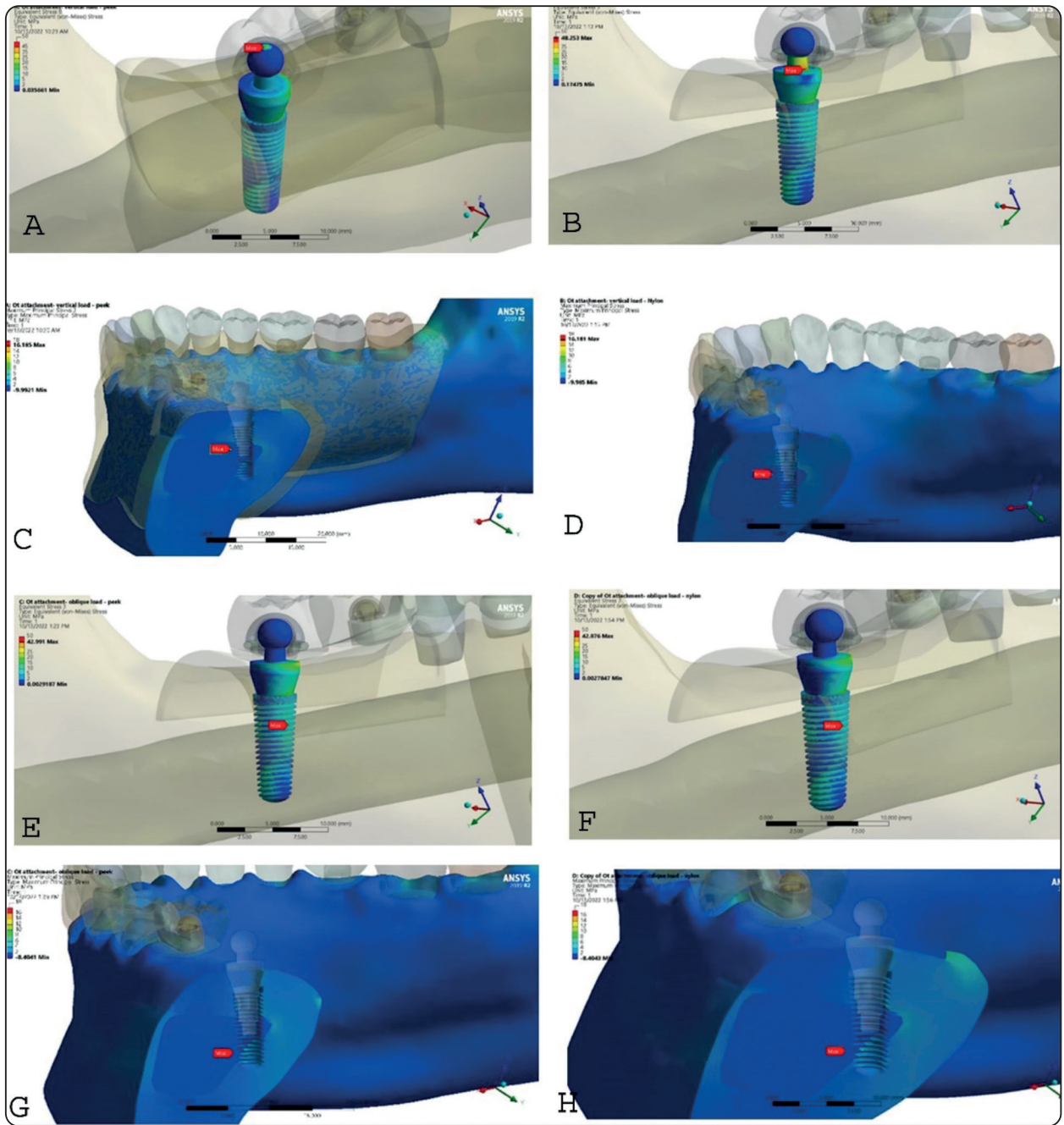


Fig.1: vertical and oblique loads on both PEEK and Nylon :A,C: vertical load on PEEK; B,D: vertical load on Nylon; E,G:Oblique load on PEEK; F,H:Oblique load on Nylon

**Stress Distribution in OT- Attachment and OT-Connector:**

*Under vertical load*, the maximum stress values recorded in OT-attachment and OT-connector in PEEK model was 129.19 and 89.2 MPa respectively, the corresponding values for Nylon model was 212.49 and 133.41 MPa showing an increase of almost 60 % compared to PEEK model (**Fig. 2 and Table 3**). For both models the maximum stresses were recorded at horizontal bar below ball attachment and at the junction of vertical arm of OT- attachment with the linguo-occlusal line angle of splinted crowns on the second premolar abutment (OT-connector) (**Fig. 2**).

*Under the oblique load*, comparable stresses were recorded for both models as shown in Table 3. For both models the maximum stresses were recorded at horizontal bar below ball attachment and at the junction of vertical arm of OT-attachment

with the linguo-occlusal line angle of splinted crown on the second premolar abutment (OT-connector) (**Fig. 3**).

**3.3 Stress Distribution in Tooth/ Implant-Supported Prosthesis:**

Under vertical load, the value of maximum stresses recorded in PEEK model was 50.098 MPa with a corresponding value of 162.58 MPa for Nylon model (**Table 3 and Fig. 4**). In PEEK model, maximum stresses were located at the maximum convexity in the mid-section of distolingual aspect of second molar while such a location was shifted to a more occlusal position in Nylon model where maximum stresses were observed at occluso-distolingual aspect of the second molar. Under oblique load, comparable stresses were recorded for both models in mesial fossa of second molar replacement tooth (**Table 3 and Fig. 4**).

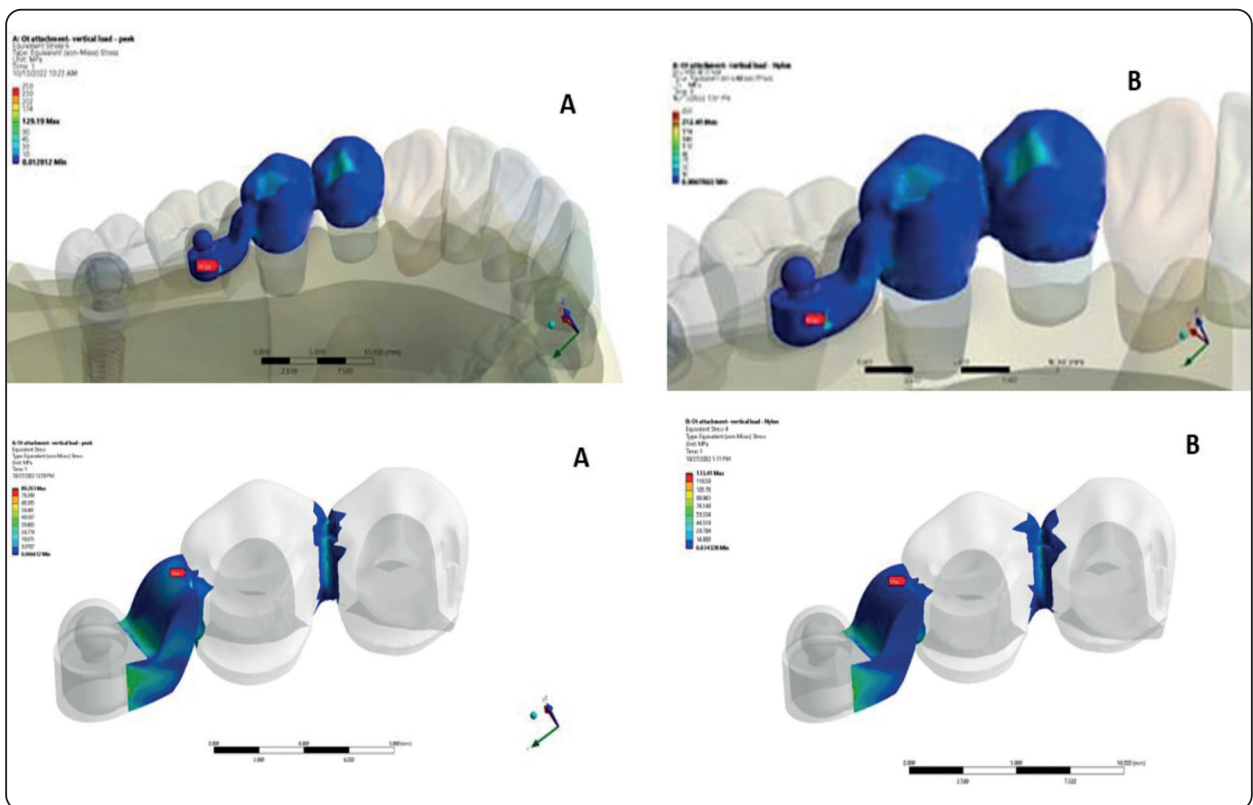


Fig. 2: Maximum von Mises stresses in OT-attachment and OT-connector under vertical load (A) PEEK model, (B) Nylon model

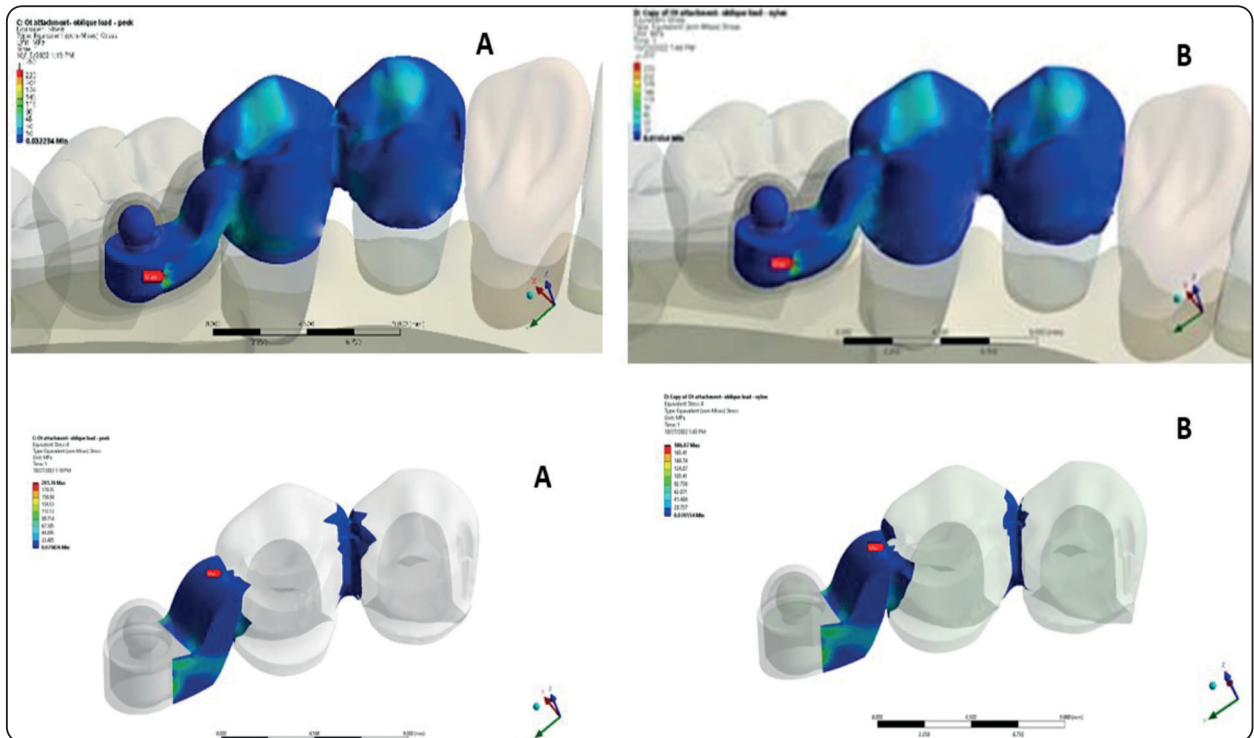


Fig. 3: Maximum von Mises stresses in OT- attachment and OT-connector under oblique load (A) PEEK model, (B) Nylon model

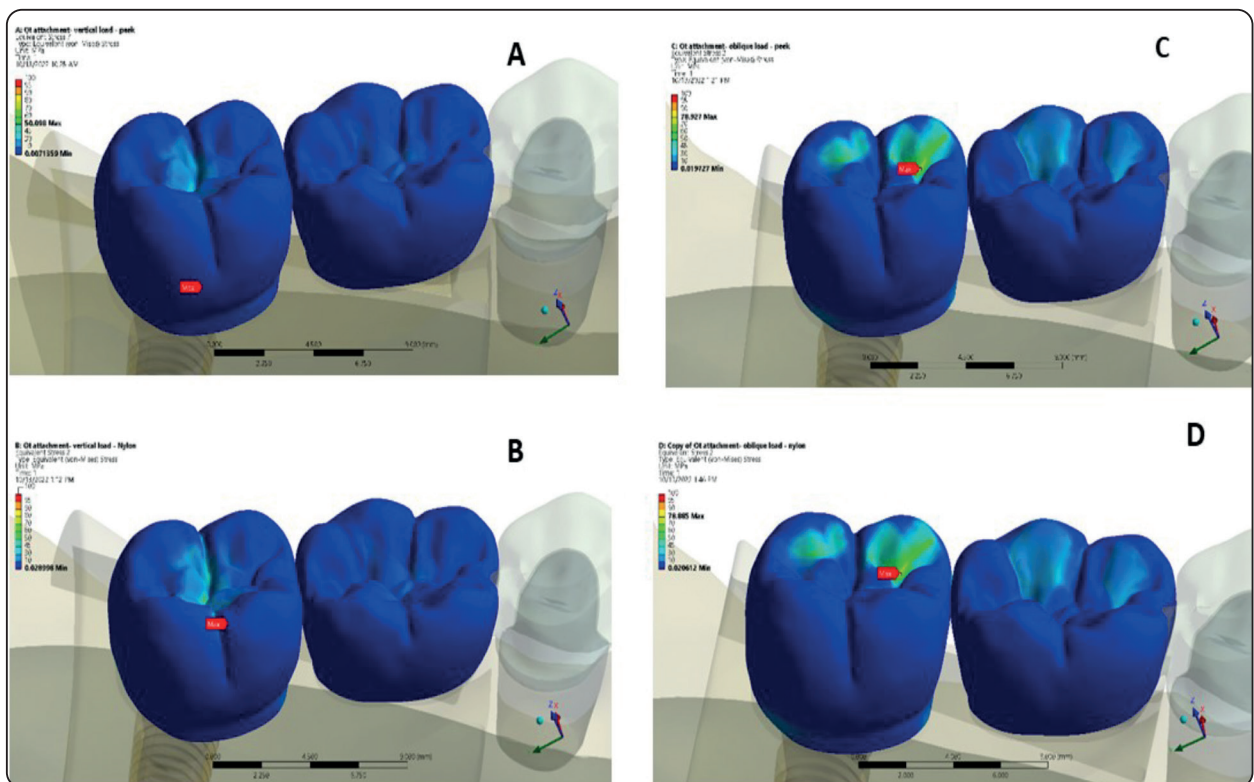


Fig. 4: Maximum von Mises stresses in tooth/implant-supported prosthesis under vertical load (A) PEEK model, (B) Nylon model. Maximum von Mises stresses in tooth/implant-supported prosthesis under oblique load (C) PEEK model, (D) Nylon model



## DISCUSSION

The present study focused on the biomechanical evaluation of stress patterns in cases of unmodified Kennedy class II cases rehabilitated with unilateral tooth/implant-supported prosthesis retained anteriorly by OT-attachment fixed to 2 splinted premolars and an implant with ball abutment placed posteriorly in the second molar area. The models compared featured both conventional nylon and PEEK retentive caps over OT ball attachment anteriorly and implant ball abutment posteriorly under both vertical and oblique loads. The implant installation was simulated in second molar area to reduce the cantilever effect and improve prosthesis support.<sup>5</sup> The null hypothesis was partially accepted as there was no difference in biomechanical behavior between PEEK and nylon retentive caps under oblique load but a substantial difference in stress values was detected under vertical load.

In all the models, maximum stresses were recorded at the OT-attachment and OT-connector compared to implant and peri-implant bone. Minimal stresses that were recorded on the implants and peri-implant bone under both vertical and oblique load can be attributed to the rotational movement which was allowed between male and female part of attachments on both ends of the implant and abutment teeth which provided a stress breaking action and allowed the teeth to move without overloading the implant.<sup>9</sup> Maximum stresses were concentrated at the horizontal, free arm of the OT-attachment which represents the only cantilevered part of the prosthesis. The presence of retentive housing whether PEEK or nylon transmitted the applied load from overlying prosthetic tooth to the horizontal unsupported arm of the OT-attachment where maximum load was recorded. Consequently, this high concentration of stresses on OT-attachment resulted in pronounced stresses on the connector presenting the junction of OT-attachment to splinted crowns on abutment teeth. In the same context,

Cella *et al.*<sup>24</sup> found maximum stress concentration in Kennedy class I cases restored with extracoronary attachment retained removable partial dentures in joining level of major connector with female part of the attachment. Posteriorly, maximum stresses were recorded in the prosthetic tooth overlying the implant abutment and stresses were further dissipated to ball abutment under vertical load and more apically to middle part of implant body under oblique forces in both PEEK and nylon models. Stresses recorded on OT attachment under oblique load in both Nylon (363 MPa) and PEEK (360) MPa model were within the fatigue limit of Cr-Co alloy of OT-attachment which is in range of 207-820 MPa.<sup>25</sup> Extrapolation of this finding to a clinical setting would imply that with continuous use of this prosthetic appliance, fatigue failure and fracture of OT-attachment under occlusal load is expected. Accordingly, such a prosthetic design without further modification to improve occlusal support and minimize stresses on OT-attachment is not indicated in an actual clinical scenario. For the sake of future studies, a wide occlusal rest with lingual circumferential ledge should be implemented in the splinted crown design to share in providing occlusal support and optimize the biomechanical behavior of whole appliance. Furthermore, in a clinical setting occlusal adjustment would be of prime importance and any occlusal disharmony that can result in stress concentration should be avoided. In an *in vivo* study on 5 patients, Ohkubo *et al.*<sup>26</sup> found increased occlusal contact area in cases of implant assisted removable partial dentures compared to conventional dentures and accordingly stressed the importance of developing proper occlusal scheme.

Though clinically vertical forces may be of less relevance however it enables better understanding of biomechanical behavior of material in a simpler setting. Increased resiliency of nylon caps resulted in the transmission of higher stresses to crown, OT- attachment and OT connector in nylon model

compared to PEEK one under vertical forces.<sup>27</sup> The difference in modulus of elasticity between the two materials was further reflected on the pattern of load distribution. Maximum stresses were focused on top of ball abutment and at neck of ball abutment in PEEK and nylon models respectively. On the other hand, when considering oblique forces which are more clinically relevant, there was no difference in magnitude or pattern of stress distribution between the PEEK and nylon models.<sup>28</sup> The lateral movement of the prosthesis in both models was minimized by contact of prosthetic teeth with distal ball abutment on one side and with the framework of OT-attachment on the other side. Such limitation to horizontal movement under oblique forces resulted in observed pattern of stress distribution at apical third of peri-implant bone. This finding is in accordance with results of Andrei *et al*<sup>29</sup> which revealed maximum stress values in unilateral removable partial dentures restored with unilateral tooth/implant-supported removable denture and retained with double ball abutments anteriorly and posteriorly under tangential component of force in apex of implant.

Although this study was initially performed to compare the biomechanical behavior between PEEK and nylon retentive caps, the results of the analysis revealed that the design evaluated in this simulation cannot be recommended for clinical use without further modifications to minimize stresses transmitted to OT-attachment. Under oblique load which is more clinically relevant there was no difference in biomechanical behavior between two evaluated retentive cap materials and it can be suggested that PEEK can be a valid alternative option to conventional nylon retentive inserts. However, before such recommendation can be made further clinical in vivo studies is still needed to investigate the retention and wear behavior of this

material in such clinical situations of unmodified Kennedy Class II cases.

In vitro nature of this study is acknowledged; however, standardization of different variables in vivo would be practically impossible. Thickness of overlying mucosa, bone consistency, crown form and root structure of supporting abutments are different not only from one patient to another but within different anatomical sites within the same patient. On the other hand, for comparative purposes the usage of finite element analysis for evaluation of biomechanical behavior of different prosthodontic designs or different materials through a mathematical model is a well-established and reliable method. As was also the case in this study, such comparative in vitro studies enable the evaluation of different prosthetic designs before it can be recommended for clinical use<sup>30</sup>.

### **Conclusions:**

Considering the limitations of this study, it can be concluded that PEEK can be a valid alternative option to conventional nylon retentive inserts for rehabilitation of unmodified Kennedy Class II cases with unilateral tooth/implant-supported prosthesis retained with double ball attachments. The prosthodontic design that was simulated in this study should be modified before it can be recommended for clinical use to improve occlusal support and minimize the stresses transmitted to OT-attachment and OT-connector.

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