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Evaluation of Stress Distribution of Zirconium Versus PEEK Extra Coronal Attachment on Supporting Structures of Lower Kennedy Class II Partial Denture

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Aim: to compare the stress distribution induced by PEEK versus zirconium employed in extra coronal attachment of partial denture in kennedy class II.
Material and methods: A virtual mandibular kennedy class II model was designed having canine and first premolar teeth as terminal abutments. Two strain gauge slots were designed on the software to receive the strain gauge rosettes. The first one was placed 1mm distal to the socket of the first premolar and the second slot 1 cm distance away from the first one. Two models were 3D printed. The attachment design was selected from software library. Crowns and attachment were milled out of PEEK and zirconia materials in the first and second models respectively. Five RPDs were constructed for each model. Bilateral load of 100N was applied. For each removable partial denture, five measurements were made. The data obtained were statistically analyzed by using unpaired t test to study the difference between group mean values ($p< 0.01$).
Results: Unpaired t test showed statistical significance between both materials in both slots during bilateral loading. The microstrain values recorded distal to the loaded abutment were less for PEEK compared to zirconia. The microstrain values recorded on the residual ridge were higher for PEEK compared to zirconia.
Conclusion: Within the limitations of this study, it was concluded that the use of PEEK as an extracoronal attachment material in attachment retained removable partial denture induced led stresses compared to zirconia.

Keywords: CAD-CAM, attachment, PEEK, Zirconia, stress analysis

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Introduction

Extracoronal attachment is a mechanical device, other than a clasp assembly, that functions as a direct retainer and provides better esthetics.[1] Resilient extracoronal attachments have been used for distal extension base cases to avoid torque of abutments and to distribute load favorably between the abutments and the residual ridge.[2]

Traditionally, cobalt-chromium (CoCr) was the most widely used material for fabrication of the attachment due to its mechanical strength, high elastic modulus and precise fitting. This material also possesses good biocompatibility and corrosion resistance.[3]Cobalt chromium has shown good clinical results when used with attachments and porcelain fused to metal FPDs.[4,5]

Nowadays, zirconia is becoming one of the most chosen materials for dental crowns and attachments because it is highly biocompatible, as the smooth surface aids to reduce plaque accumulation. The material also promotes a healthy tissue response. zirconia is suitable for patients with metal allergies or who would prefer to have metal-free restorations to exclude darkening around the gingival area. Moreover, zirconia has a fracture toughness and flexural strength that is twice as high as those of feldspathic ceramics, making it suitable for use in posterior restorations.[6–8]

Polyaryletherketones (PAEK) has been recently introduced as a promising alternative to ceramic materials, including polyetheretherketone (PEEK) material.[6]Compared to the metals that are used in dentistry, PEEK is more stable, biocompatible, lighter and has better esthetics and a reduced degree of discoloration. It has been reported to have unique resilient properties, shock absorption, biocompatibility, corrosion resistance, minimal creep and modulus of elasticity similar to bone.[6,9–11] Several Studies showed less stresses induced by PEEK when used as posts in endodontically treated teeth, clasps fabrication and frameworks over implants.[12–16]

Different methods for fabrication of extracoronal attachments can be used as casting, pressing and milling.[6,17] The development of computer-aided design and manufacture (CAD/CAM) techniques helped extensively in medical fields. They have many technological advantages in designing and manufacturing of the dental prosthesis that significantly improve the efficiency and achieve good results in clinical practice compared with traditional manual techniques. [18,19]

Different devices for analysis and evaluation of distribution of the stresses can be used as strain gauge ,finite element and photoelastic analysis.[12,20,21]Different materials; co-cr, zirconia and peek have been investigated as an attachment material in many different studies.[20–24]

However, to the best of our knowledge, the stresses induced by these materials when used as an extracoronal attachment material in removable partial denture were not examined and mentioned in the literature. So, this study was conducted to compare the stresses induced by zirconia and PEEK when used in the fabrication of the extracoronal attachment in removable partial denture. The null hypothesis that there was no difference in the stresses induced by zirconia and PEEK (BioHPP) when used as extracoronal attachment.

Materials and methods

This study was conducted using a digitally produced (Kennedy class II) mandibular arch model with the canine and first premolar as a principle abutments. Two models were used in this study. In the first model the attachment was made out of PEEK, while in the second model was made out of Zirconia. Five removable partial dentures were made in each group.

Model construction:

For both models following steps were done. Educational stone model was prepared with the canine and first premolar as a principle abutment. Preparations for rest seats were made in the second premolar and first molar on the contralateral side using size two round bur (MANI, MANI, INC, Tochigi, Japan) to receive double aker clasp later.

On the other hand, canine and first premolar in the edentulous side were prepared using rounded tip rotatory diamond (MANI, MANI, INC, Tochigi, Japan), with heavy chamfer finish line for receiving the crown.

The cast and the teeth were then scanned (DOF swing scanner, DOFlabs, Seoul, South Korea). They were sprayed properly with occlusion spray for the recognition of trouble spots; Titanium dioxide –free spray (Occlutec green, Renfert, Germany) and scanned and a standard tessellation language (STL) file was generated on the software (Exocad Dental CAD, Exocad Inc. Darmstadt, Germany).

On the software, the canine and the first premolar teeth were subtracted from the cast by boolean subtraction, then virtual superimposition of the prepared mandibular canine and first premolar were superimposed virtually in their corresponding sockets in the previously scanned mandibular model. A space of 0.25 mm was left between inner surface of the socket and the canine root surface simulating the periodontal membrane space. A thickness of 2 mm layer was cut back from the crest of the scanned model to represent the future mucosa.

Two strain gauge slots were designed on the software to receive the strain gauge rosettes. The first one was placed 1mm distal to the socket of the first premolar and the second slot 1 cm distance away from the first one. The slots were made parallel to each other.

After these modifications were done, the STL file was exported to the 3D printing machine (form 2 3D printer, formlabs, Somerville, Massachusetts, United States). The model and two pairs of the prepared teeth were 3D printed. Printing for cast and dies were done from acrylic resin material.

The 3D printed mandibular canine and first premolar were then scanned (DOF swing scanner, DOFlabs, Seoul, South Korea). Two fully anatomic splinted crowns were designed (Exocad Dental CAD, Exocad Inc. Darmstadt, Germany) virtually on the prepared abutments. The lingual surface of the first premolar crown was prepared to have a circumferential shoulder at the junction between the middle and gingival parts.

The attachment (vario soft 3 mini sv, bredent, Germany) was chosen from the library, attached to the distal wall of the first premolar crown in proper position. The attachment was placed on a line bisecting the angle between the crest of the ridge and the sagittal plane of the model. (Fig.1)

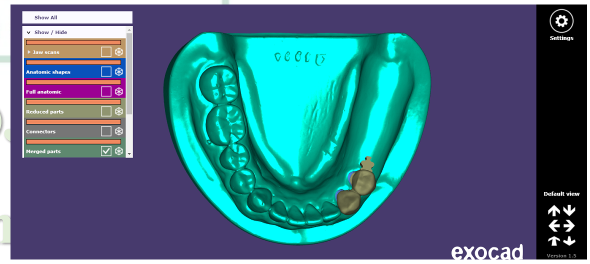

Figure 1: The attachment

In the first model, crowns and attachment were milled out of PEEK (BioHPP, blank size 14, Brecam Biohpp, Bredent, Germany), then checked for perfect fit with prepared abutments and cemented in place with cavex temporary cement (Cavex, Netherlands). Both the abutments with its overlying crowns were seated in their corresponding socket in the model. In the second model, crowns and attachment were milled out of zirconia (katana, Kuraray Noritake Dental, Inc, Okayama, Japan) and sintered. The zirconia crowns were sintered in the furnace (TABEO-1/M/ZIRKON-100, Mihm-vogt, Germany) with classic sintering system, finished, polished and glazed. Zirconia crowns were then checked for perfect fit with prepared abutments and cemented in place with cavex temporary cement (Cavex, Netherlands).

The 3D model was duplicated to form identical refractory cast for the fabrication of the removable partial denture. The combined denture base was chosen for the free end saddle. The double aker clasp assembly was designed for the second premolar and the first molar on the other side. The lingual bar was used as a major connector to connect the denture parts with each other. The edentulous ridge was covered with 2 mm thick light body silicone rubber base impression material (Speedex, C-silicone, Coltene, Switzerland) for mucosa simulation. Female part (Bredent, Germany) was then picked up with resin material (Duralay, Interfloor, Haslingden, Lancashire, UK).

The strain gauges (kyowa strain gauges, Tokyo, Japan); used in this study had a length of 1 mm, width 1mm and resistance 120 Ohm. The strain gauges were installed in their grooves on the distal aspect of the abutment, the crest of the ridge and bonded in position with delicate layer of cyanoacrylate adhesive (Amir Alpha, Cairo, Egypt). The terminals of the strain gauge wires were attached to a four-channel strain-meter (Kyowa, Kyowa Electronic Instruments Co., Ltd, Tokyo, Japan) to measure the microstrains induced by the applied load.

The model was placed on the lower plate of the universal testing machine (Lloyd LRX; Lloyd Instruments Ltd., Fareham, UK). For bilateral loading, a metal bar was placed on the occlusal plane between the right and left denture bases in the region of the first molar. The forces were delivered to the center of the metal bar using the loading pin of the loading device. The magnitude of the applied load was 100 N and was amplified from 0 to 100 N at a constant rate of 0.5 mm/min. For each model, five removable partial dentures were constructed. For each removable partial denture, five measurements were made. Five minutes recovery period was permitted between the measurements. (Fig.2)

Figure 2: The Universal testing machine

Once the load was completely applied, the data were analyzed using the software (PCD-300A Kyowa Electronic Instruments Co., Ltd, Tokyo, Japan) and microstrain values were recorded. All data were collected and tabulated.

Results

The recorded data was tested for normal distribution using Shapiro –wilk test for normality. The data was normally distributed, so unpaired t test was used.

During bilateral loading, compressive strains developed in the two groups in the first and second slots. Unpaired t test showed statistically significant difference between the Zirconia and PEEK groups.(Table.1)

For the first slot, the mean value for the model A was found to be (-16.67), S.D was (10.7), value of the test (T value) was (8.6614). The mean value for the model B was found to be (-183.86), S.D was (132.43), value of the test (T value) was (8.6614). The calculated amounts of stresses induced by both materials were statistically significant $P< 0.01$. The recorded P value was (0.00001).

For the second slot, the mean value for the model A was found to be (-9.4), S.D was (2.91), value of the test (T value) was (-12.23). The mean value for the model B was found to be (-5.29), S.D was (4.011), value of the test (T value) was (-12.23). The calculated amounts of stresses induced by both materials were statistically significant P< 0.01. The recorded P value was (0.00001).

Table 1: Comparison between the two models regarding the microstrain values recorded during bilateral loading

	PEEK		Zirconia		T value	P-value
	X(με)	SD	X(με)	SD		
distal to the abutment (first slot)	-16.67	10.7	-183.86	132.4	8.6614	.00001
1cm away from the abutment (second slot)	-9.4	2.91	-5.29	4.011	-12.23	.00001

X: mean, SD: standard deviation

Discussion

This in-vitro study was conducted because laboratory studies are more easily controlled and can yield more accurate results especially when the experiments are concerned with comparative values. In vitro study can be considered more valid as the test can be repeated under the same conditions where the subject under study would be the only variable.[25]

A mandibular model with unilateral free end saddle (kennedy class II) was used for this study because the lower denture biomechanical design is more problematic compared to the upper one. The fact of the smaller mandibular denture bearing area compared to the maxillary one makes the greater amount of residual ridge reduction occurs in the mandible and hence the coverage area required for denture retention and stability is reduced.[26]

Extracoronal attachments were used for their enhanced retention for the partial denture, esthetics, masticatory efficiency, less decay of the abutment teeth and more patient satisfaction.[1,2,27] The attachment used has good shear distribution allowing protection for the periodontal structures and the remaining teeth.[22,28]

Many studies examined retention and effect of PEEK and zirconia in different prosthetic solutions on supporting structures but there is lacking data about the stresses induced by them as extracoronal attachments materials in removable partial dentures.[17,22) So this study was conducted to compare the stresses induced by such materials when used as an extracoronal attachment in removable partial denture.

In this study, sound natural teeth (canine and first premolar) were prepared with deep chamfer finish line to meet the requirements of zirconia and PEEK crowns preparation.[6]

A three-dimensional model was digitally designed to allow standardization between the two models. Moreover, digital designing has excellent accuracy, less time consuming and less manufacturing errors when compared to conventional technique.[29–31] Moreover, digital designing allowed Standardized placement of strain gauge slots in relation to the abutments. Furthermore, the slots were even and smooth helping to minimize the possibility of obtaining strains that may result from rough surfaces.[32]

The models and abutment teeth were digitally printed to have high accuracy, standardization and minimal amount of internal stresses as they are fabricated layer by layer.[31,32]

Mucosa simulation was done to mimic the viscoelastic behavior of the fibrous mucoperiostium that covers the residual ridge. The thickness of the simulated mucosa was 2 mm approximately. Addition silicone rubber base material was used for this purpose as it has viscoelastic character, lowest dimensional changes values and minimum permanent deformation.[33,34]

The crowns and attachments were digitally milled to have better accuracy, adaptation, internal fit, marginal precision and less manufacturing errors than conventional technique.[6,35]Preparation on the lingual surface of the first premolar was done to receive the lingual guiding arm.The lingual guiding arm have been used for its bracing effect and sharing some of loads transmitted to the supporting structures.[36]

BioHPP was chosen due to the combination of its biocompatibility and mechanical properties. The elastic modulus of BioHPP lies in range of 4000 MPa is very similar to the human bone elasticity so the chewing forces could be cushioned. The shock absorbing property could also reduce stresses transferred to the abutment teeth and the supporting structures.[9,10]

Zirconia was chosen for its esthetic and mechanical properties. Zirconia exhibits sufficient strength because the fracture toughness and bending strength are increased by a stress-induced transformation-toughening mechanism. Moreover, it is highly biocompatible, as the smooth surface helps to reduce plaque accumulation.[7,8]

For the removable partial denture design, a double Aker clasp was used on the dentate side of the dental arch to enhance retention, cross arch stabilization and reciprocation.[37] Lingual bar was used as major connector because in addition to its simplicity, it has minimal soft tissue coverage; this decreases the plaque accumulation and increases soft tissue stimulation.[38]

Cross arch stabilization was achieved through the major connector and clasps of the other side. Cross arch stabilization reduces the buccolingual rotation of the prostheses , provides better force distribution and transmits less strains on the abutments.[37]

All the strain gauges used in the study exhibited the same dimensions, resistance and gauge factor in order to obtain the same level of sensitivity to the applied load. The thickness of the cement layer used as a bonding agent was the minimum required to avoid the effect of thick cement layer on the obtained data. The cement used was reported by the manufacturer to exhibit efficiency when used in minimum thickness.[33,39]

The load applied was about 100 N in order to correspond with the average chewing force required for most type of food. Five readings were made for each RPD. Five minutes of rest were given to the strain gauges to be in zero balance and to allow complete rebound of the resilient structures between the readings.[33]

The null hypothesis in this study was rejected as there was statistically significant difference in the microstrain values between the two attachments materials. However, peek showed less microstrains in both slots than zirconia. All the microstrains were compressive in nature.

The shock absorbing property of the PEEK material may account for the less microstrain values recorded when used as an attachment material.[6,9,11,12] Their elastic modulus being closer to bone and acrylic compared to zirconia may have also helped with better stress distribution.[10,14]

This result came in accordance with the results of Diego et al, who reported that peek framework delivered less stresses to the implants when compared to metal framework. However, PEEK delivered more stresses to the bone trabeculae in the same case when compared to more rigid materials.[16] Tekin et al also showed that the use of PEEK posts created less stress compared to the glass fiber posts and explained that this results due to PEEK modulus of elasticity.[13]

In addition to that El said et al, reported that peek showed better results when used as a housing for a milled bar compared to co-cr material. This could be explained in the light of reduced modulus of elasticity, dampening of occlusal forces and shock absorption property of PEEK female housings. In consequence, decreased incidence of wear, fracture and renewal.[9]

On the other hand, the stresses recorded in the second slot were higher for PEEK compared to zirconia. This can be explained in the light of the results reported by Diego et al, that the shock absorbing property of PEEK is limited to the site of its presence. However, distant sites received higher stresses when PEEK was used compared to other rigid materials in implant supported bridges. [16]

Conclusion

Within the limitations of this study, it was concluded that the use of PEEK as an extracoronal attachment material in attachment retained removable partial denture induced led stresses compared to zirconia.

Recommendation

It is recommended to perform clinical studies using PEEK and zirconia as an extracoronal attachment material in removable partial dentures to figure out their effects on the supporting structures and the various outcomes during their clinical performance.

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