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INFLUENCE OF DIFFERENT BAR ATTACHMENT MATERIALS ON STRESS DISTRIBUTION AROUND TWO INTERFORAMINAL DENTAL IMPLANTS: AN IN VITRO STUDY

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ABSTRACT

Statement of problem: Metal-free materials were developed to be used as alternatives to metal alloys for fabrication of bar attachments. As the attachment must provide favorable stress distribution around implants, studies evaluating the influence of metal-free materials compared to metal alloys on stress distribution around dental implants are needed.

Aim: to compare the effect of three different bar materials on stress distribution around two interformainal implants.

Material and methods: 18 epoxy models of edentulous mandibular arches were used in which two parallel implants were inserted bilaterally at the canine areas in each model. The models were then divided equally into three groups according to the material used for the bar fabrication. In group I, six bars were fabricated from cobalt chromium alloy, in group II, six bars were fabricated using CAD-CAM milled zirconia, and in group III, six bars were fabricated using CAD-CAM milled polyetheretherketone. A universal testing machine was used to apply bilateral loading on each bar and the microstrain developed around implants was recorded using strain gauges.

Results: A statistically significant difference in strain values was observed between the three groups with the highest strain values recorded in the cobalt chromium bar group, followed by the zirconia bar group, while the lowest strain values were observed in the polyetheretherketone bar group (P=.001).

Conclusions: Metal-free materials used for bar construction appear to be promising alternatives to cobalt chromium as they show a more favorable stress distribution, which positively affects the survival rate of implants.

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INTRODUCTION

Complete denture is considered the simplest and cheapest treatment option for edentulous patients. However, adaptation of complete dentures is a relatively complex process.[1] Stability and retention of dentures diminish over time due to the ongoing bone resorption which results in functional compromise, especially with the mandibular dentures.[2,3]

In the McGill consensus 2002, it was well established that placement of two interforaminal implants to retain a mandibular overdenture is the standard treatment option for edentulous patients who have problems with their complete dentures,[4] and this was also reiterated by the York consensus in 2009.[5]

Various attachments have been used for retaining overdentures to implants.[6,7] The type of attachment is considered an essential factor for implant success as it influences the stresses transmitted to the implant during function.[8,9] One of the controversies during planning for implant-supported overdenture is to decide whether to splint the implants or not. A systematic review concluded that implant-supported overdentures retained by bar attachments were successful in terms of prosthetic retention and patient satisfaction, while unsplinted implants supporting overdentures required more prosthetic maintenance.[10] In addition, Stoker et.al., stated that after eight years follow-up, the two implants connected with a bar attachment in the mandible were the best combination with the least complications.[11]

Many materials were recommended for bar fabrication, and the most commonly used is cobalt chromium (Co-Cr) alloy. However, with the increased demand for esthetic and biocompatible materials and for patients who are allergic to metals or who dislike the metallic taste and metal display, new alternative metal-free materials including zirconia and polyetheretherketone (PEEK) have been developed. It has been suggested that the choice of materials is based on their biomechanical behavior, the stress distribution around the implants, and restoration serviceability.

Zirconia is considered the strongest and toughest ceramic that exhibits high properties. Compared to Co-Cr alloy, zirconia displays better biocompatibility with higher mechanical properties, including high wear and fracture resistance and extremely high tensile and compressive strengths.[12,13] Bühler et al., fabricated two individual zirconia bars to support mandibular overdentures; and stated that no galvanism occurred due to the metal freedom. Moreover, it showed higher patient acceptance and good hygiene ability because of its superior esthetics and smooth surface.[14] PEEK is a metal-free thermoplastic polymer with low molecular weight and high biocompatibility.[15] The linear aromatic semi-crystalline structure of PEEK has exceptional physiochemical properties including elasticity and hardness.

Bar attachments are traditionally fabricated using the conventional casting technique. With the computer-aided design and computer-aided manufacturing (CAD-CAM) technology, the overdenture bar can be more precisely milled using different materials, including metal, ceramics, and polymers.[16]

Strain gauge is a method used to evaluate the stress distribution around implants, which depends on recording of the microstrain through alteration of the electrical resistance.[17,18] It converts a resistance change to an electrical voltage, which can be measured with high accuracy at the place of the strain gauges.[19]

To the authors' knowledge, there is a lack of evidence in the literature comparing the metal and metal-free materials used for bar attachment fabrication as regard to the stress distribution around dental implants. This study aimed to compare metal (Co-Cr) and metal-free materials (zirconia and PEEK) used for bar attachment fabrication regarding strain induced around two interforaminal implants. The null hypothesis of the study was that there would be no difference between the three bar materials.

MATERIAL AND METHODS

This in vitro study was conducted on 18 ready-made epoxy resin dental models (Ramses medical products factory) representing edentulous mandibular arches. For all models, two dummy implants (3.5 mm diameter and 10 mm length) were inserted bilaterally at the canine regions. The inter-canine distance on the model was 22 mm, which simulates the distance between two natural mandibular canines. With the aid of a surveyor (Dental Lab Surveyor; Saeshin precision IND.CO.), the two implants were installed parallel to each other and perpendicular to the ridge.

Bar attachments were used to splint the two implants together. According to the material used for the bar fabrication, the 18 models were divided into three equal groups with six models in each group. For the Co-Cr bar attachment group, two plastic castable abutments were attached to the implants and a ready-made plastic bar was used to determine the length of the bar that would be used, and the excess was cut. Two retaining slots were made on the mesial side of each abutment to allow easy fixation and positioning of the bar in the proper occlusogingival direction with proper relation to the ridge.

Complete fixation of the bar to the abutments was done using duralay (Duralay, Reliance Dental Manufacturing Co.). After the polymerization of the duralay, assembly of the plastic bar with the two plastic abutments was removed from the model and cast into Co-Cr alloy (Niadure, DFS Diamon) using the conventional casting technique. Then, the final Co-Cr bar-abutment assembly bars were finished, polished, and screwed onto the models (Fig.1).

All the Co-Cr bar-abutment assemblies were then scanned (inEos X5 Dentsply Sirona) to be used as a blueprint for fabrication of zirconia and PEEK bars (Fig. 2). The 3D images of the scanned bars were checked for accuracy (Fig. 3). For the zirconia bar attachment group, the bar-abutment assembly were milled using a milling unit machine (Zirconzahn, Milling unit M1) then, they were sintered using a sintering furnace (Zirconzahn 600/v2) at 1600° for 12 hours. The finished zirconia bar-abutment assemblies were then screwed on the models as shown in figure 4. For the PEEK bar attachment group, the same steps were repeated, then the PEEK bar-abutment assemblies were milled and screwed directly on the models (Fig. 5).

Fig. (1): Cobalt chromium bar-abutment assembly

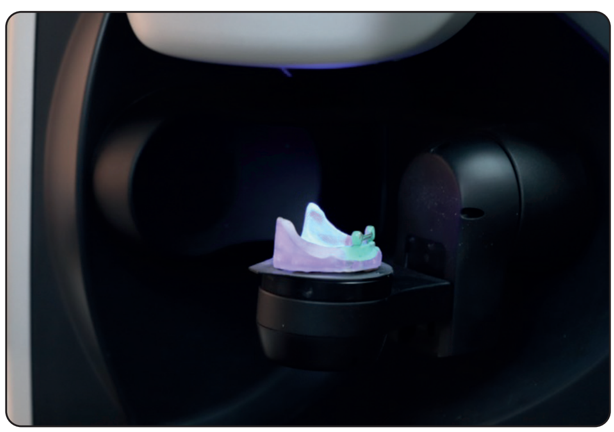

Fig. (2): Scanning of Cobalt chromium bar-abutment assembly

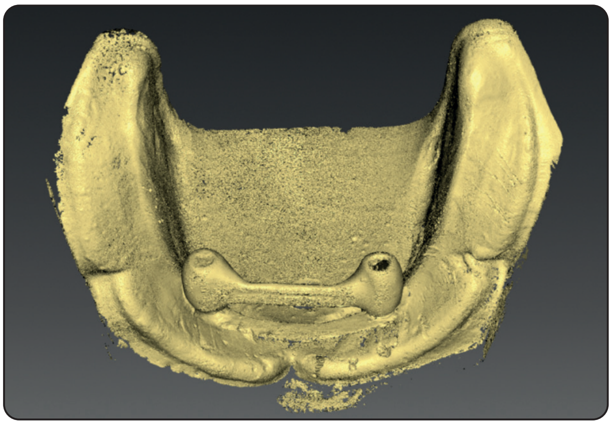

Fig. (3): 3D image of the scanned Cobalt chromium bar-abutment assembly

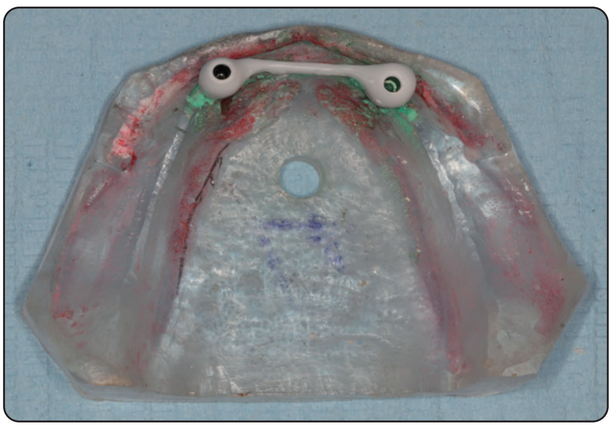

Fig. (4): Finished CAD-CAM milled zirconia bar-abutment assembly screwed on model.

Fig. (5): Finished CAD-CAM milled PEEK bar-abutment assembly screwed on model

On each model, eight self-protected linear strain gauges (KFG-1-120-C1- 11L1M2R, KYOWA) of a gauge factor 2.13 ± 1%, a gauge length 1 mm and a gauge resistance of 119.6 ± 0.4Ω were used. For accurate monitoring of the effect of the applied load on implants, four channels were prepared at each implant's labial, lingual, mesial, and distal aspects. A cyanoacrylate adhesive (CC-33A) was used to bond the strain gauges and light pressure was applied against the bonded gauges for five minutes using a large ball burnisher. All strain gauges were left for 24 hours to allow complete setting of the cyanoacrylate adhesive.[20] All the wires were labeled indicating the surface to be measured. A universal testing machine (Mecmesin, Multi Test5-XT) connected to a computer was used to apply a vertical compressive load of 50 N with a crosshead speed set at 10 mm/min. The load application was bilateral using the T-shaped load applicator. Simultaneous and even contacts between each bar and T- shape load applicator on both sides were achieved. All the strain gauges were zeroed and calibrated before loading. The strain gauge sensors were connected to a multichannel strain meter (Data Logger model TDS-150) to calculate the microvoltage output converted into microstrain using a special software (Kyowa PCD 300 A). This procedure was repeated for each bar in the three groups. At least five minutes were left between each reading to allow heat dissipation from the sensors.[21] The recorded microstrain from the 18 models was subjected to statistical analysis.

The data were collected and statistically analyzed using a statistical software program, IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). The Kolmogorov-Smirnov test was used to verify the normality of distribution of variables.[22] ANOVA was used to compare between the groups and was followed by the Tukey post hoc test for pairwise comparisons. Significance level was judged at 5%.

RESULTS

The mean strain values developed after bilateral load application of 50 N in the labial, lingual, mesial, and distal aspects of the 2 implants were summed and compared between the groups, as shown in Table 1. The comparison of recorded strain values at the 4 aspects revealed a significant difference between the 3 groups (*P*=.001), where the highest loading strains were recorded in the Co-Cr group, followed by the zirconia group and the lowest stresses were noted in the PEEK group.

TABLE (1): Comparison between studied groups regarding strain values

	Cobalt Chromium (n=6)	Zirconia (n = 6)	PEEK (n = 6)	K	*P*
Labial (μm/m)					
Mean ± SD.	9.81 ± 7.0	5.81 ± 7.22	4.21 ± 4.012	12.52*	0.001*
Median (Min. – Max.)	10 (0 – 25)	5 (0 – 20)	4 (0 – 15)		
Lingual (μm/m)					
Mean ± SD.	29.86 ± 21.95	28.62 ± 29.45	22.0 ± 18.3	6.10*	0.031*
Median (Min. – Max.)	20 (0 – 65)	15 (0 – 85)	12 (0 – 50)		
Mesial (μm/m)					
Mean ± SD.	7.68 ± 6.4	1.05 ± 1.99	1.2 ± 0.96	8.11*	0.006*
Median (Min. – Max.)	3.5 (2 – 16)	0 (0 – 5)	0 (0 – 2)		
Distal (μm/m)					
Mean ± SD.	15.33 ± 7.47	4.43 ± 4.56	4.01 ± 5.01	5.98*	0.036*
Median (Min. – Max.)	15 (10 – 25)	5 (0 – 15)	4 (0 – 15)		
Average (μm/m)					
Mean ± SD.	15.67 ± 5.03	9.97 ± 6.71	6.6 ± 7.9	12.91*	0.001*
Median (Min. – Max.)	10 (2 – 50.0)	10 (0.75 – 30)	7 (0 – 25)		
Sig. bet. groups.	P_1=0.021*, P_2=0.001*, P_3=0.031*				

K: Kruskal-Wallis one-way ANOVA (Non parametric test)
Pairwise comparison bet. each 2 groups was done using Post Hoc Test (Duncan's method)
P: P value for comparing between the studied groups
P1: P value for comparing between Cobalt Chromium and Zirconia
P2: P value for comparing between Cobalt Chromium and PEEK
P3: P value for comparing between Zirconia and PEEK
**** Significant difference at P at 0.05***

DISCUSSION

As it was proved by McGill and York consensus that two interforaminal implants are the standard option for retention of mandibular overdentures, two implants were placed bilaterally in the canine region as this region showed high implant success rate when loaded by overdentures.[23] Epoxy resin models were used as it has 20 GPa elastic modulus, which is similar to that of bone.[24]

Based on the results of a finite element analysis study made by Georgiopoulos et al., implants shorter than 10 mm did not alter the strain field. Subsequently, 10 mm length was chosen as it is considered as an adequate length to obtain optimum stress distribution around the implants.[25] Regarding to the diameter of the implants, it was reported that there should be at least 1 mm of bone at buccal and lingual walls of the selected implant site to ensure sufficient bone thickness and blood supply around the implant for predictable survival.(26) This explains why implant with 3.5 mm diameter was chosen in the model with width of 7.5 mm at the canine region.

Selection of the attachment system for overdenture has a direct effect on the survival rate of implants.(6) The choice of bar attachment in this study was based on many previous studies, reporting that bar attachments have superior characteristics as they can favorably distribute stresses between implants, provide rotational movements, have higher wear resistance, and greater mechanical stability.(7-9,11)

In the current study, CAD-CAM technology was used for designing and milling zirconia and PEEK bars based on research data, which recommended that CAD-CAM technology facilitates the production of superior restorations with acceptable marginal adaptation.(27)

The stresses on implants should be measured using in vivo strain gauge method but unfortunately, owing to the difficulty in standardization and repeatability of the obtained values for strain measurement in vivo, the current study was conducted in vitro to overcome many technical difficulties in connecting the strain gauges to the dento-alveolar region intraorally.(17,18) The wires of gauges were embedded in prepared channels to prevent their accidental dislodgement. Magnitude of the applied load was 50 N, which simulates a moderate level of the biting force of an edentulous patient on an implant-supported overdenture.(28)

Based on our findings, the null hypothesis was rejected as a statistically significant difference was found between the three bar materials. The PEEK material showed the least strain values, while Co-Cr bars showed the highest strain values. This was consistent with Ehab M et.al., who compared the effect of Co-Cr and PEEK bars on stress distribution in implant-supported mandibular overdenture and concluded that the Co-Cr bars were subjected to higher stresses than PEEK under a bilateral loading of 60 N.(29)

Regarding the strain values, zirconia showed higher values than PEEK and this did not agree with Emera et.al., who conducted an in vitro study to compare the recorded stress values of all PEEK, all zirconia, and zirconia-PEEK telescopic attachments under a bilateral loading of 70 N and found that, all zirconia transmitted less stress than PEEK attachments.(15) This may be attributed to the different attachment designs as bar attachments were used in the current study, while Emera et al used unsplinted telescopic attachments.(15) Thus, bar attachments may distribute loads in a different way than telescopic attachments.

Despite the significant difference between the three groups during bilateral loading, it was observed that the microstrain values around the two implants were higher in the Co-Cr bar group followed by zirconia bars followed by PEEK bars. This may contribute to the fact that the materials have different chemical structure. Cobalt chromium is a metal alloy, PEEK is a polymeric material, while zirconia is a ceramic material; therefore, their performance was different. Zirconia is a tough ceramic material, so the bar transmits more stress on implants than PEEK. The favorable stress distribution of the PEEK bars may be attributed to the cushioning effect of PEEK material as it is a metal-free high density thermoplastic polymer, which is light in weight.(30) In addition, PEEK has 4GPa modulus of elasticity, so it is elastic as bone, absorbs the occlusal forces, and reduces the stresses transmitted to implants preserving the osseointegration with time which in turn reflects on the survival rate of implants.(31)

CLINICAL IMPLICATIONS

Bar attachment materials affect the amount of stress transmitted around dental implants. PEEK and zirconia bars can be considered good alternatives to Co-Cr as they show a more favorable stress distribution, which positively affects the survival rate of implants.

Future studies are needed to evaluate the retention and wear of PEEK and zirconia bars and correlate the findings within in vivo studies to evaluate the effect of bar attachments on peri-implant bone loss.

CONCLUSIONS

Based on the findings of this in-vitro study, the following conclusions were drawn:

1. The attachment bar material influences the amount of load transmitted to the implants supporting mandibular overdentures.
2. PEEK bar attachments showed lower strain values with more favorable stress distribution when compared to Co-Cr and zirconium bar attachments.
3. PEEK material is a promising alternative to Co-Cr as it has a load-cushioning capacity, which minimizes the stress transmission allowing its successful use as a bar retaining implant-supported overdentures.

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