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Effect of Two Different Digitally Constructed Bar Materials on The Supporting Structures of Implant Retained Mandibular Overdenture (In-Vitro Study)

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Aim: The aim of this study was to evaluate which bar material (BioHPP or Cobalt Chromium) induced less stresses on the supporting structures of implant retained mandibular overdenture.

Materials and methods: Completely edentulous mandibular educational cast was scanned. Designing an STL file including; implants beds, mucosal space and vertical slots for strain gauges was done. A bar joint design was selected & STL files were transferred to 5-axis milling machine to mill bars as follow: group I: Six bars were milled from BioHPP blank, group II: Six bars were milled from cobalt chromium blank. For each model, four strain gauge sensors were placed and a universal testing machine were used to apply a static load of 100N bilaterally between lower second premolar and first molar then unilaterally on the right side. The mean and the standard deviation of the recorded readings were collected, tabulated, and statistically analyzed.

Results: The result of this study showed no significant difference between the two groups regarding bilateral loading as the mean micro strain was 314.83 &313.5 µm/m for group I & II respectively.Under unilateral loading, the results showed that the mean micro strain in the loaded side was 495.16 &493.83 µm/m for group I & II respectively and the result was statistically non-significant.

Conclusion: Within the limitations of this study, it could be concluded that:

-BioHPP and Cobalt-Chromium milled bars have no differences regarding micro strains developed in the supporting structures either upon bilateral or unilateral loading in implant retained mandibular overdenture.

Keywords: BioHPP, Co-Cr, Implant, Overdenture, CAD/CAM

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Introduction

An effective prosthetic treatment depends on evidence-based comprehensive treatment planning, in which several elements should be considered, including patient preferences and needs, anatomic constraints and prosthetic limitations. And as a result, removable implant-assisted prostheses could be the treatment option for a significant proportion of patients. Evidence shows that individuals with mandibular implant assisted dentures are more satisfied and have a better oral health-related quality of life than do those with conventional dentures.[1-3]

The attachments that are used in conjunction with implants were found to enhance the retention, stability, as well as the support of overdentures together with the implants, thus extending their longevity. A wide variety of commercially available attachment systems are used to in the process of connecting implants to overdentures whether it's by splinting or un-splinting the implants. Bar attachment is one of the popular attachment types as it offers better transmission of forces between the implants due to it's primary splinting effect, load sharing, better retention and the least post insertion maintenance. [4,5]

Cast Cobalt-Chromium (CoCr) bars have been used in implant supported overdentures, not only as a solution to increase the strength of an acrylic prosthesis but also to equally distribute load barring forces across the implants. However, the traditional bar fabricated via conventional casting procedures often produced a misfit between implants and implant bars. So, In order to prevent that, commercial laboratories switched to using the CAD-CAM technology for creating the prosthetic framework.[6,7]

Advances in the CAD-CAM technology have brought about production techniques, which are faster and more precise, increasing the efficiency of the fabrication of implant bars , as well as greatly improving seating predictability. In turn, this led to the introduction of new materials that could be precisely milled for the fabrication of dental prostheses.[8]

Polyetheretherketone (PEEK) and PEEK based materials like BioHPP, have been recently introduced in dentistry as a framework material for metal-free dental prostheses. This is as they present favorable properties such as excellent biocompatility, good mechanical properties, good thermal and chemical resistance, white color as well as being lightweight to permit the fabrication of lighter metal-free frameworks.[9-11]

Comparing it to rigid framework materials such as zirconium oxide and metal alloys, PEEK has a low modulus of elasticity of 4 GPa, and has similar elasticity to bones, that provides a cushioning effect together with reduction of stresses transferred to the abutment teeth. Despite the wide spread of PEEK in clinical practices, only a few studies are available focusing on the use of this material for CAD-CAM prostheses.[12,13]

It is known that the mechanisms of stress distribution and load transfer to the implant/bone interface are critical issues that can affect the success rate of implants. Overload can lead to mechanical complications and bone loss.[14,15]

So, this study was conducted in order to compare stresses induced on the supporting structures of implant retained mandibular overdenture between digitally constructed Cobalt Chromium and BioHPP bar materials

Materials and Methods

This study was conducted on a 3D models simulating a lower edentulous mandible with two implants in the intra-foraminal region and a bar attachment to retain mandibular implant overdenture.

Model construction:

Completely edentulous mandibular model was scanned via desktop scanner (3Shape D850, Denmark), then a Standard Tessellation Language (STL) file was generated and imported to an implant planning software (OnDemand3D, Cybermed Inc., Daejeon, Korea) for virtual implant placement. Implant fixtures (JDentalCare, Italy) with size (3.7x13mm) were chosen from the library and virtually placed in the model, to make the crest of the implant flushing with the model edge with 20 mm distance between them. A model creator software (Materialise magics, Leuven, Belgium) was used to create two slots for strain gauges attachment parallel to the long axis of the implant and 1mm away from the implant in the distal and the mesial of each implant bed. Then a two mm layer thickness was removed from the scanned model crest, as it represent the future mucosa. The final design of the model was printed (six models for each group) with 3D printer (ULTRA 3SP, EnvisionTEC GmbH, Gladbeck, Germany). Figure 1,2

Figure 1: Final model design

Figure 2: Final 3D printed model with implants.

A tray for mucosa simulator was designed to be closely fit over the model using a special software program (In2guide cybermed, seoul, korea). It was printed from a biocompatible resin material (Grey model resin, formlabs, Somerville, USA). Mucosa simulation was done with a rubber base material (Multisil-Mask soft, Bredent, senden, Germany). Hence reproduction of the gingiva on the working model was achieved. Implants were placed at their places in the working models.

<u>Scanning and designing:</u>

Titanium inserts with 3mm height and 0.5mm shoulder finish line were screwed to the implant fixture in the working model . A scan body (J dental scan body, JDentalCare s.r.l, Italy) was seated tightly over them and scanned to transfer the three-dimensional implant position to the CAD software (Exocad GmbH, Darmstadt, Germany). JDental titanium insert was chosen from digital libary, then the scan body was automatically converted into a Ti base and the cement gap between the restoration and the Ti base was automatically set into 60 µm.

A bar joint design (Rhein83 USA) was selected from the software library, a screw retained bar (2mm in width and 2.4 mm in height) was designed connecting between the two titanium inserts and centralized over the ridge to make the final length of the bar 20mm with its flat surface above the ridge by 2 mm and its round surface facing occlusally. STL files were transferred to the CAM software and milling was done using a 5-axis milling machine (Inlab MC X5, Sirona Dentsply, Bensheim, Germany.) to mill bars as follow:

For group I: Six bars were milled from BioHPP blank. Figure 3a

For group II: Six bars were milled from cobalt chromium blank. Figure 3b

A universal primer (Ivoclar Vivadent; Schaan, Liechtenstein) was applied to the pretreated surfaces of the titanium insert and to the bars using a micro-brush and left to react for 60 seconds then dried with a stream of oil-free air. A thin layer of multilink hybrid abutment resin cement was then applied to the titanium inserts at each model. Removing of excess cement was done by a micro brush then the bars were also screwed to their respective implant in the working model using a screwdriver and torque wrench under 30 Ncm torque then they were retightened after 10 minutes to avoid preload screw loosening.

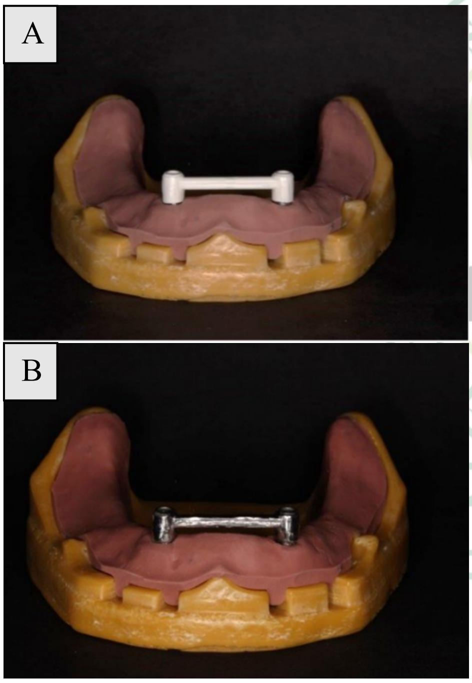

Figure 3: a-BioHPP bar on the working cast, b- Cr-Co bar on the working cast

Overdenture construction and clip attachment picking up:

The waxed-up denture was fabricated by adapted a sheet of modeling wax to the ridge of the working model, then acrylic resin teeth were set following the normal anatomy. A duplicate cast was fabricated upon which the laboratory procedures were performed, an open top impression of the 3D printed cast was made by polyether impression material (3M™ ESPE™, USA), using transfer copings and impression posts. The waxed up denture was then transferred to the duplicated stone model, flasked and processed into pink heat cure acrylic resin (Acrostone Dental & Medical Supplies, Egypt).

For picking up the clip attachment, undercuts beneath the bar were blocked out with wax and a space was created in the fitting surface of the mandibular overdenture. The clips were placed on the bar and auto-polymerizing acrylic resin was applied in the fitting surface of the denture opposite to the bar, then the overdenture was placed on the model. Firm steady pressure was applied on the overdentures bilaterally until complete curing of the resin occurred.

Strain gauge analysis:

Four strain gauges (Kyowa, Japan) were positioned at their places in each model at the distal and mesial aspects parallel to the long axis of each implant, and the strain gauges were bonded with a delicate layer of Cyano Acrylate base adhesive cement.

A universal testing machine (LLOYD Universal Testing Machine, U.K) was used for applying 100 N vertical loads using a T-shaped load applicator on the denture teeth bilaterally between the distal aspect of lower second premolar and mesial aspect of lower first molar for five times on each bar. Figure 4

After fifteen minutes the same load was applied unilaterally for five times on the right side to represent the working side using I bar shaped load applicator and the mean micro strain values of the five load applications in the loaded and unloaded sides were taken.

The mean and the standard deviation of the readings (micro strain) of each loading point were calculated for statistical analysis.

Results

Statistical analysis was performed with IBM® SPSS® Statistics Version 26 for windows. Data was represented by mean and standard deviation (SD) values. One-way

ANOVA test was used to study the effect of the different bar materials on micro strains (µm/m). $P \leq 0.05$ was considered for statistical significance. The results were presented in tables (1-3).

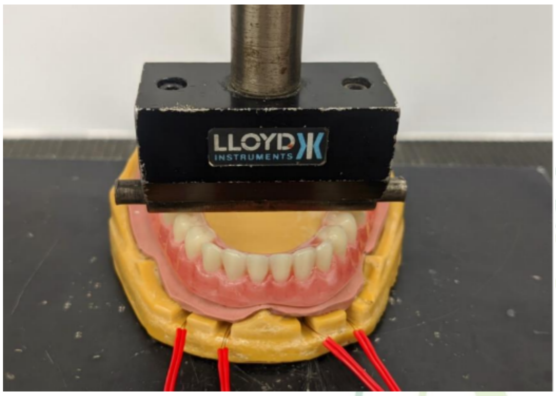

Figure 4: T-shaped load applicator between second premolar and first molar

Table 1 Mean, standard deviation (SD), and P value of bilateral load for two studied groups

Groups	Mean	SD	95% Confidence Interval		P value
			Lower Bound	Upper Bound	
Group I (BioHPP bar)	314.833	4.54	309.601	318.065	0.739
Group II (Co-Cr bar)	313.500	5.50	303.268	320.732	

*Significant ($p \leq 0.05$) non-significant ($p>0.05$)

Table 2 Mean, standard deviation (SD), and P value of unilateral loading (the loaded side) in both groups

Groups	Mean	SD	95% Confidence Interval		P value
			Lower Bound	Upper Bound	
Group I (BioHPP bar)	495.16	8.011	489.135	501.198	0.735
Group II (Co-Cr bar)	493.83	4.875	487.802	499.865	

*Significant ($p \leq 0.05$) non-significant ($p>0.05$)

Table 3 Mean, standard deviation (SD), and P value of unilateral loading (the un-loaded side) in both groups

Groups	Mean	SD	95% Confidence Interval		P value
			Lower Bound	Upper Bound	
Group I (BioHPP bar)	160.333	3.461	156.971	163.696	0.090
Group II (Co-Cr bar)	156.323	3.777	152.122	159.452	

*Significant ($p \leq 0.05$) non-significant ($p>0.05$)

A-Bilateral load:

-Comparison between the total bilateral micro strains in both groups:

Total micro strain was measured by taking the average of mesial and distal strain in both implants for each bar and showed in table 1.

The mean micro strain in group I (BioHPP) was 314.83 ± 4.54 µm/m while in group II (Co-Cr) was 313.5 ± 5.50 µm/m. Statistical analysis showed non significant difference between the two bar materials on bilateral loading.

B-Unilateral load:

1-Comparison between micro-strains in the loaded side of both groups after unilateral load:

It was measured by taking the average of mesial and distal micro strain in the loaded side in both groups. The results were showed in table 2.

The mean micro strain of the loaded side in group I (BioHPP) was 495.16 ±8.011µm/m while the mean micro strain in the loaded side in group II (CoCr) was 493.83±4.875 µm/m and statistical analysis showed that there was statistically non-significant difference between the two studied groups.

2- Comparison between micro-strains in the un-loaded side of both groups after unilateral load:

The mean micro strain of the unloaded side in group I (BioHPP) was 160.333 ±3.461µm/m while the mean micro strain in the unloaded side in group II (Co-Cr) was 156.323± 3.777µm/m and statistical analysis showed that there was statistically non-significant difference between the two groups as shown in table 3

Discussion

This study was conducted as in vitro study to allow for better control over variables which usually occur in the clinical evaluation due to alteration in oral hygiene, strength of masticatory muscles, age and sex with different patients. [16]

Titanium implant was used in this study instead of using an analog, to be able to distribute the loads applied in a similar manner to the oral conditions. The implant used was 3.7 mm in diameter and 13 mm in length to resemble the average size of implants used in the lower anterior region. They were inserted in a 3D printed model as it was done in a previous study conducted by

Salaita et al[17] for standardization and accurate positioning of the implant.

The use of the 3D technology with its software gives the researcher full authority to determine every wanted detail like the dimension of the implant beds and the distances between the strain gauges grooves and the implants which should be even and smooth which will minimize the possibility of obtaining incremental apparent strains that would result from curved surfaces. [18]

Mucosa simulation was created to mimic viscoelastic behavior of the fibrous mucoperiostium covering the residual ridges. Addition silicone rubber base was used for this purpose as it has the lowest values of permanent deformation ,dimensional changes, , and viscoelastic qualities. [19.20]

The design showed titanium-to-titanium contact as, the titanium insert is in contact with the implant platform & abutment screw to reduce the risk of damage at implant abutment interfaces. They combine the advantages of both screw retained and cement retained implant supported restorations. As they have the strength and the precise fit of a titanium-to-titanium connection, they also allow retrievability and ease of removal for hygiene maintenance, repair of fractures or screw loosening over life. [21]

100N loading magnitudes which represent the normal masticatory forces were applied and was directed between the second premolar and the first molar since this is reported to be the chewing area where most patients perform chewing. [22] Also, as much of the chewing activities are carried out unilaterally, unilateral loading was performed. [23]

The results of this study distinctly revealed that recorded micro strain values of the both groups were lower than the human bone micro strain threshold (3000 µm/m). [24] These results conveyed that when the two models were subjected to bilateral loading, stresses provided to the supporting implants under the prosthesis was reduced and the load was distributed on the alveolar residual ridge and the implants in comparison with unilateral loadings, while under unilateral loadings the stresses were concentrated at the loaded implant and ridge. This finding could be due to the wide distribution of forces over a square area under bilateral load, therefore involving more planes and to the favorable support achieved with the quadrilateral design and due to its potential to dissipate the stresses uniformly between both the ridge and the implants with its splinting effect. While under unilateral loadings, the rotational movement of the prosthesis concentrates the stresses at the loaded implants and ridge. [25]

This study showed that the use of BioHPP bar caused favorable load distribution to the alveolar ridge, and shifting the stresses to the implant supporting structures as it is elastic as bone with 4 GPa modulus of elasticity, so can reduce stresses transferred to the abutment teeth. Also due to its insolubility in water and low reactivity with other materials, it could be more suitable for patients allergic to Cr-Co, and sensitive to the metallic taste of conventional Cr-Co. Also, the white color of BioHPP materials provides a different esthetic approach than the conventional metal display does. Additional advantages of this polymer material are good wear resistance, low plaque affinity, and high polishing qualities. [26]

Upon applying unilateral load both groups showed no significant difference between them in the loaded sides and in the unloaded sides and this can be justified by the fact that this prosthesis is an implant assisted one so part of the load is distributed and absorbed by the mucosa and the bone underlying the edentulous ridge. This was in accordance with a study done by Yoo JS et al[27] concluding that vertical pressure is transmitted to the mucous membrane through the implant assisted overdenture and the overdenture works like a snowshoe; thus, it decreases the stress per unit area that is applied to the implant.

Conclusion:

Within the limitations of this in-vitro study, it could be concluded that:

-BioHPP and Cobalt-Chromium milled bars have no differences regarding micro strains developed in the supporting structures either upon bilateral or unilateral loading in implant retained mandibular overdenture.

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