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Effect of CAD/CAM Constructed BIOHPP versus Zirconia Frameworks Reinforced Maxillary Complete Denture on Fracture Resistance (*In vitro* Study)

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Abstract

AIM: This study was carried out to investigate the effect of reinforcing material on the fracture resistance of computer-aided design/computer-aided manufacturing (CAD-CAM) bio high-performance polymer (BIOHPP) and zirconia-reinforced maxillary complete dentures under fatigue loading.

MATERIALS AND METHODS: BIOHPP and zirconia framework-reinforced maxillary complete dentures were fabricated using silicone molds and acrylic resin and control group dentures were prepared with no reinforcement (n = 7). Cyclic loading was applied using chewing simulator; then, fracture resistance was measured by universal testing machine.

RESULTS: After cyclic loading, none of the dentures showed any cracks or fractures. During fracture resistance testing, all unreinforced dentures experienced complete fracture, while the framework-reinforced dentures showed acryl fracture only without the framework. BIOHPP reinforced maxillary dentures showed the highest fracture resistance (1705.70 ± 213.75), followed by the zirconia-reinforced maxillary dentures (1690.10 ± 135.40) ($p < 0.001$).

CONCLUSION: Maxillary complete dentures reinforced by CAD/CAM BIOHPP and zirconia frameworks showed higher fracture resistance under cyclic loading. Maxillary complete dentures reinforced by BIOHPP framework showed higher fracture resistance than those reinforced by zirconia. The reinforced dentures maintained their shape even after fracture, indicating the possibility of easier repair.

Introduction

Acrylic resin (polymethyl methacrylate) has been the most widely used denture base material since 1940’s, its favorable properties such as excellent appearance, ease in processing, and repair contribute to its success as a denture base material. However, acrylic resin has some drawbacks as low impact strength and low fatigue resistance. The fatigue failure occurs when the denture base deforms repeatedly by the occlusal forces, while the impact failure occurs when the dentures are accidentally dropped on a hard surface [1]. Therefore, reinforcing materials are required to improve the mechanical properties of complete dentures. In clinical practice, metal frameworks are the primarily used as reinforcing material to improve the fracture resistance, volume stability, and precision of complete dentures. However, metal frameworks reinforced dentures are heavier and require more complicated fabrication processes; the lost wax technique used to fabricate metal framework shows many drawbacks compared to resin bases; also, the possibility of hypersensitivity cannot be excluded as they are made of alloys [2].

Recently, dramatic advances in computer technology have enabled new techniques that replace the lost-wax method, termed dental computer-aided design, and computer-aided manufacturing (CAD/CAM). Such systems have been used to design and fabricate dental prostheses, therefore broadening the range of available materials. CAD/CAM systems have been used to fabricate crown and bridge copings and removable prosthesis frameworks [3]. In the present study, BIOHPP and zirconia CAD/CAM milled frameworks were used as reinforcement for maxillary complete dentures. BIOHPP is considered a variant of PEEK (polyether ether ketone) that contains about 20% ceramic filler with grain size between 0.3 and 0.5 microns results in constant homogeneity, extremely good polishing properties and high mechanical properties [4]. Furthermore, it has comparable elasticity to the bone, shock absorbing effect, low specific weight, high biocompatibility, and no corrosion. In addition to high fatigue strength, no viscoelastic fractures and low plaque accumulation. All of which makes it a suitable material for frameworks fabrication [5].

Zirconia has a significant impact on dentistry due to its biocompatibility, high esthetics, and strength. Recently, zirconia replaced metals in dental prostheses and improved the mechanical properties of complete denture bases as its addition in nanoparticles form improved the transverse strength of the heat polymerized denture bases.

In vitro studies of zirconia specimens showed a flexural strength of 900–1200 MPa and a fracture toughness of 9–10 MPa [6].

This study was conducted to evaluate the fracture resistance of both BIOHPP and zirconia frameworks reinforced maxillary complete dentures in comparison to the conventional acrylic complete denture after using chewing simulator.

Materials and Methods

A silicon mold was created from a standard edentulous maxillary die (dental study model 402U, GC, Japan), Type IV dental stone (Die-Keen, Heraeus-Kulzer, Germany) [3] was poured in this mold to fabricate 21 corresponding plaster casts. A total of 21 master casts were fabricated and randomly divided into three groups (n = 7):

- Unreinforced heat cured acrylic resin-based (control group).
- CAD/CAM BIOHPP framework reinforced acrylic denture-based.
- CAD/CAM zirconia framework reinforced acrylic denture-based.

The maxillary master cast was scanned using an extra oral scanner[1] (Figure 1), where the scan was uploaded to dental wings software[2]. Then, partial denture module was used to design the framework, which extended 2 mm buccally, labially, and palatally on the residual ridge, with a palatal extension extending from the molar area on the right side to the molar area on the left side with 1 mm tissue stops on the fitting surface. The framework design was added to the scanned model (Figure 2), and then, the following steps were carried out to start the milling process: (1) Adding a new blank, (2) importing standard tessellation language (STL) file, (3) nesting, and (4) adding supporting bars then it was exported to CAD/CAM machine.

1 DS Mizar extraoral scanner Germany
2 Straumann group brand Switzerland

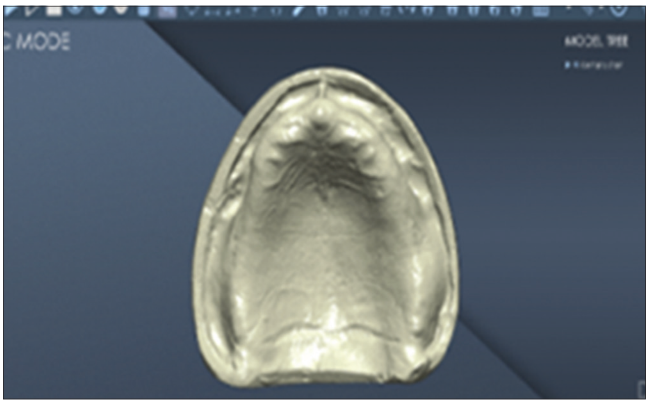

Figure 1: Scanned master cast uploaded to software

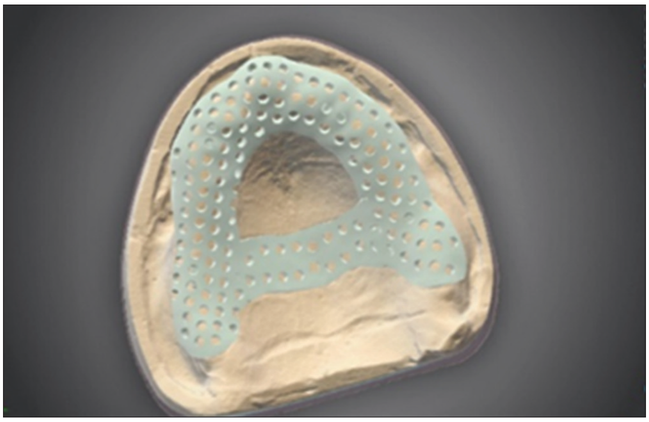

Figure 2: Framework design on the master cast

The BIOHPP blank used had the thickness of 16 mm[3], while the zirconia blank[4] was 22 mm in thickness, both blanks were then milled using five-axis dental milling machine. In case of zirconia, complete sintering in the furnace at 1350°C to 1500°C was done to achieve its final shape. The frameworks were then seated on the casts to check their fit and accuracy before denture processing. To avoid frameworks deformity or movement during denture base packing, a quick-drying glue was applied on the frameworks' stops to stabilize the framework on the cast and the resin was packed carefully.

The dentures were processed using heat cured acrylic resin following the conventional long polymerization cycle, then were finished and polished in the usual manner (Figure 3).

Figure 3: Processed dentures with the frameworks

Epoxy resin[5] casts were made using the silicon mold. To add mucosa simulation to the casts were prepared as following, approximately 2 mm thickness was reduced from every cast using a round bur of 2 mm

3 Biohpp blank bredent Germany
4 Zirconia blank Aconia st China
5 Bredent exakto form epoxy Germany

diameter for pitting the edentulous area, followed by uniform reduction to the denture bearing area and the limiting borders [7], [8].

Three grooves were made on a duplicate cast to represent the 2 mm thickness of the tissue simulator material then a vacuum sheet was processed over it to construct a stent with three tissue stops to ensure uniform thickness of the tissue simulating material. An adhesive for bonding the mucosa simulation was painted over the prepared cast and mucosa gingival mask[6] was injected and pressed over the cast to simulate mucosa.

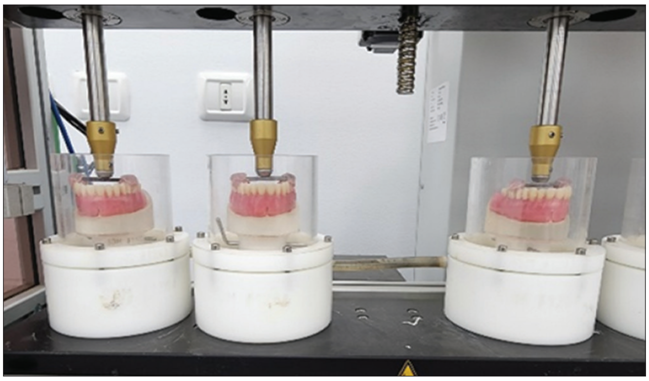

Figure 4: Sampels mounted inside chewing simulator chamber

A Chewing Simulator[7] was used to apply dynamic cyclic loading by means of a stylus falling at the center of a metal plate that was attached previously to the occlusal surface of complete dentures (Figure 4) [9]. The software parameters were set at 60 mm/sec speed, 3 mm vertical path, 0.7 mm horizontal path, and 1.6 Hz frequency. Each denture was subjected to bi-axial cyclic loading with a total of 250,000 cycles and was tested under the same conditions, that is, filling the specimen chamber with saliva at a load setting of 50 N [10], [11].

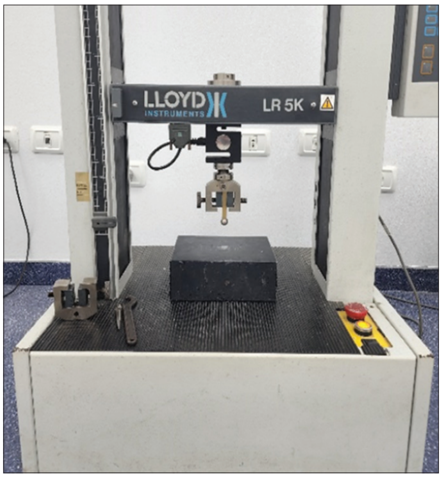

Figure 5: Universal testing machine using to measure fracture resistance

A universal testing machine[8] (Figure 5) was used to record the fracture resistances of the complete

6 Addition svernetzends Zahnfleischmasken-Silicon(bredent)
7 CS-44-SD Mechatronic chewing simulator Germany
8 LLOYD INSTRUMENT LR5K

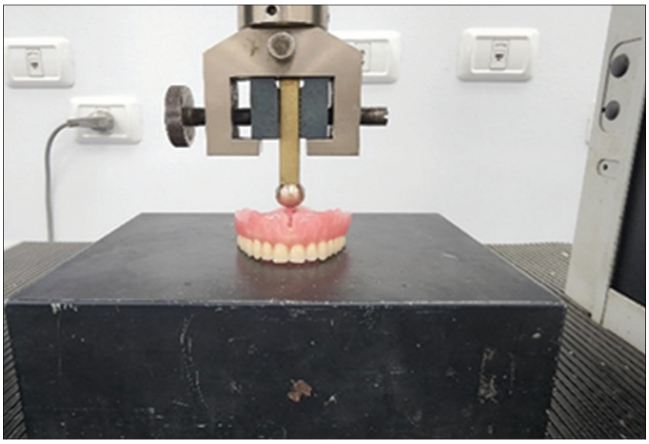

Figure 6: Maxillary denture under load

dentures reinforced with different materials. Each denture was positioned with the occlusal surface oriented downward [9], and the load was applied at a crosshead speed of 5 mm/min using a stainless-steel ball of 1.5 cm in diameter (Figure 6) on the tissue surface at the point where the palatal midline of the complete denture crossed the line connecting the second premolars on each side [2], until fracture occurred (Figures 7-9).

Statistical analysis

A power analysis was designed to have adequate power to apply a statistical test for the null hypothesis that there is no difference in the fracture resistance between the different tested groups. By

Figure 7: Unreinforced maxillary denture fracture

adopting an alpha level of (0.05), a beta of (0.2), that is, power = 80% and an effect size (f) of (0.912) that was calculated based on the results of a previous study[9]; the predicted sample size (n) was a total of (21) samples (i.e., 7 samples per group). Sample

9 Im, So-Min, *et al*. “Comparison of the fracture resistances of glass fiber mesh-and metal mesh-reinforced maxillary complete denture under dynamic fatigue loading.” The journal of advanced prosthodontics 9.1 (2017): 22-30.

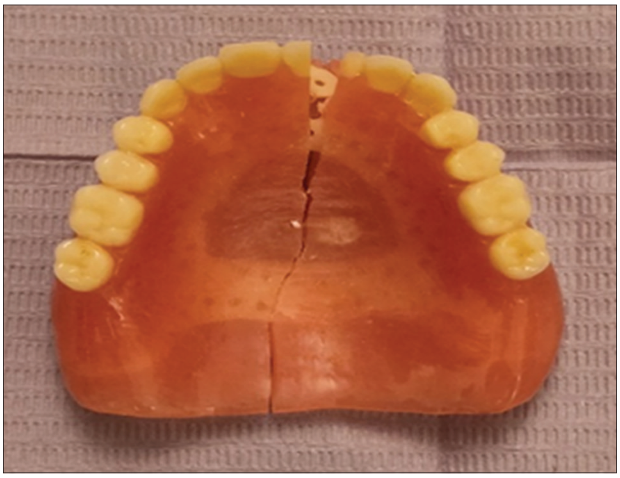

Figure 8: Fractured zirconia reinforced maxillary denture

size calculation was performed using G*Power version 3.1.9.7[10]

To evaluate the differences in the fracture resistances of the reinforcing materials, one-way analysis of variance (ANOVA) was performed followed by Bonferroni *post hoc* test for intragroup comparisons. The significance level was set at $p \leq 0.01$. Statistical analysis was performed with R statistical analysis software version 4.1.3 for Windows[11].

Figure 9: BIOHPP reinforced maxillary denture showing only cracks not complete fracture

Results

Regarding the fracture resistance, the descending order was the BIOHPP reinforcement, followed by zirconia reinforcement, then the unreinforced control group, with a statistical significance ($p < 0.001$).

The mean and standard deviation (SD) values of the fracture resistance (F) for different dentures' reinforcements are presented in table one, showing a significant difference between the different groups ($p < 0.001$). The highest value was found in BIOHPP reinforcement, followed by zirconia reinforcement, while the lowest value was found in the unreinforced denture. *Post hoc* pairwise comparisons showed that the unreinforced denture had a significantly lower value than other groups ($p < 0.001$) (Table 1).

Discussion

Denture base acrylic resin is subjected to many different types of stresses, these stresses could be divided into intraoral stresses that could be caused by repeated masticatory forces that lead to fatigue phenomena and extraoral high-impact forces that may occur due to dropping the prosthesis, leading to denture base fracture [12]. Therefore, the resistance of denture to fracture imposes a great challenge.

Adding reinforcing materials to the conventional acrylic denture during its fabrication is one of the methods used to decrease the possibility of denture fracture, to increase the denture's lifespan, and to improve patients' satisfaction. This study was conducted to evaluate the effect of different reinforcement materials on the fracture resistance of maxillary complete dentures.

BIOHPP and zirconia frameworks designed and milled by CAD/CAM technology were used as complete denture reinforcement, as they provide mechanical reinforcement and a thicker palatal area which improves the patients' comfort [3]. Using new developments in dental materials and computer technology have led to the success of contemporary dental CAD/CAM technology [13].

For standardization, a silicon mold was made in order to be used to pour three identical maxillary casts for denture fabrication and three epoxy resin casts for chewing simulator to represent maxillary arch.

Flexible silicone was used as a mucosa simulator while using the chewing simulator as it resembles the normal mucosa in its viscoelastic properties, it has the lowest value of dimensional change and permanent deformation; also, it provides a stable non-movable model surface. An adhesive was used for bonding the mucosa simulator to the underlying model [7], [8].

The Chewing Simulator was used to apply a dynamic cyclic loading by means of a stylus falling at the center of the metal plate that was attached previously to the occlusal surface of complete denture; a metal plate was chosen instead of an acrylic one as it has a better stress distribution according to the previous studies [9].

10 Faul, Franz, *et al*. "G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences." *Behavior research methods* 39.2 (2007): 175-191.

11 R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Table 1: Mean and SD values of F for different denture materials

Fracture resistance (F) (mean ± SD)			F-value	p-value
BIOHPP	Zirconia	Acrylic		
1705.70 ± 213.75[A]	1690.10 ± 135.40[A]	1324.10 ± 154.83[B]	15.90	<0.001*

SD: Standard deviation, F: Fracture resistance, [A,B]: Different alphabetic indicating significance

The settings of the chewing simulator were adjusted at a load setting of 50 N and the software parameters were set at 60 mm/sec speed, 3 mm vertical path, 0.7 mm horizontal path, and 1.6 Hz frequency according to the setting parameters used in the previous studies [10], [11]. After using chewing simulator, the load was applied using a universal testing machine to each maxillary complete denture. The downward load applied along the midline of the tissue surfaces of the denture was designed to be equivalent to the upward load on both sides, combined with the unyielding support in the center of the palate [9]. Loading was applied at a crosshead speed of 5 mm/min using a stainless-steel ball of 1.5 cm in diameter and then the fracture resistance of each denture was measured [2]. The results of fracture resistance showed that the BIOHPP-reinforced denture had the highest fracture resistance followed by zirconia-reinforced denture and the least was the unreinforced acrylic denture. This agreed with the previous studies which showed that the BIOHPP used as a framework material for complete dentures resulted in decrease denture deformation responsible for midline fracture.

However, BIOHPP frameworks with a thickness of 1 mm could offer only a slight reinforcement to complete dentures, and in this conducted study, the thickness was 1.5 mm which resulted in better reinforcement for complete dentures [14].

Furthermore, the results of the present study agreed with Hossam *et al*., study which revealed that BIOHPP framework showed a significantly higher fracture resistance than zirconia [15].

The present study results were consistent with Muhsin *et al*., study who evaluated denture bases fabricated by milled or thermo-pressed PEEK and PMMA, which showed that PEEK denture bases had higher impact and tensile strength than PMMA.

Thus, PEEK could be regarded as a suitable material for denture bases, providing resistance to notch concentration and fracture [16].

Conclusion

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

1. CAD/CAM BIOHPP and zirconia frameworks used as reinforcement for maxillary acrylic complete dentures showed higher fracture resistance under cyclic loading.
2. Maxillary complete acrylic dentures reinforced by BIOHPP framework showed higher fracture resistance than zirconia framework-reinforced dentures.
3. The BIOHPP and zirconia-reinforced dentures maintained their shape even after fracture, indicating the possibility of easier repair.

Recommendation

From this research, it is recommended that further clinical trials take place with longer follow-up periods and it is highly recommended to investigate different materials.

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