EGYPTIAN
DENTAL JOURNAL
www.eda-egypt.org

Vol. 70, 377:385, January, 2024

Print ISSN 0070-9484 • Online ISSN 2090-2360

Fixed Prosthodontics and Dental Materials

Submit Date : 08-09-2023 • Accept Date : 02-10-2023 • Available online: 10-01-2024 • DOI : 10.21608/EDJ.2023.235049.2712

A COMPARATIVE STUDY OF DIFFERENT CAD/CAM MATERIALS REINFORCING IMPLANT RETAINED OVERDENTURE BASE MATERIAL (AN IN VITRO STUDY)

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ABSTRACT

Background: New types of CAD/CAM materials are currently used on wide scales to reinforce implant-retained overdentures as a substitute for conventionally non-reinforced overdentures; thus, further studies are needed to validate these materials.

Methodology: Fifteen implant-retained overdentures were constructed. Three completely edentulous 3D-printed models were obtained, in which 6 laboratory implant analogs were secured in the position of teeth 33 and 43 with ball attachment. The 3D-printed models were divided into 3 groups. Group 1 received five mandibular implant retained overdentures reinforced with poly-ether-ketone-ketone (PEKK) meshwork. Group 2 received mandibular implant-retained overdentures reinforced with fiberglass-reinforced composite resin (FRC) meshwork. Group 3 received five mandibular implants retained overdenture reinforced with cobalt chromium (CoCr) meshwork. A universal testing machine was used to evaluate the fracture resistance of the fifteen overdentures, and the recorded data were collected, tabulated, and statistically analyzed.

Results: There was a significant difference between group 3 and groups 1 and 2, while there was no significant difference between groups 1 and 2. The greatest fracture load was found in Group 1 (4310 ± 214.57), followed by Group 2 (4261 ± 218.41), and the lowest fracture load was found in Group 3 (3877 ± 201.74).

Conclusion: The (FRC) and (PEKK) meshworks provided better alternatives to CoCr. meshwork as a reinforcement material in heat-cured acrylic resin implant retained overdentures.

KEYWORDS: Denture fracture – poly ether ketone ketone - cobalt chromium – fiber-reinforced composite resins - CAD/CAM

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INTRODUCTION

The use of overdentures supported by two implants has been considered as the standard option for rehabilitation of a fully edentulous mandible. This method has been proven to be safe, and clinically effective over the long term. [1]

The fracture of the unreinforced base of an implant- retained overdenture is one of the most common problems, especially when attachments are utilized over the implants. This could be attributed to a lack of enough inter-arch space required for the proper layer thickness of the denture base material, as well as the denture base weakening following the usual attachment pick-up technique. [2-4]

Polymethyl methacrylate acrylic resin (PMMA) is currently the material that is most frequently utilized in the fabrication of denture bases. Due to its advantageous mechanical characteristics, simplicity of processing, exact fit, stability in the oral environment, increased aesthetics, ease of repair, and use with reasonably priced equipment, PMMA is still in use today. Despite having all these benefits, it also has a significant drawback: low fracture resistance, which renders it fragile and prone to fractures when falling or as a result of wear and tear from prolonged use PMMA's fracture resistance needs to be strengthened. [5,6]

When examining various strategies to enhance the properties of acrylic denture base materials, the enhancement of fracture resistance to prevent breakage was an important concern. This entails chemically changing acrylic resin and reinforcing acrylic dentures with additional elements, including metal wires, metal meshwork, and non-metallic meshwork, from the recently introduced polymers. [7,8]

The addition of cobalt chromium meshes produced better fracture resistance and is still the standard method to reinforce overdentures. However, its addition will increase the denture weight and might lead to extra stresses around the implants. [9,10]

The lightweight framework material polyetherketone-ketone (PEKK) was created with excellent biological properties. It is a member of the group of engineering polymers and was developed to replace zirconia and metal alloys in implant frameworks. Because PEKK has a less inflammatory response than PMMA, it can be utilized to treat people with metal allergies. [11,12]

Due to its 20% higher amount of titanium dioxide particles and the presence of a ketone group, PEKK has 80% stronger compressive strength and better fatigue properties than PEEK. Given its excellent performance, the PEKK material has the potential to serve as a permanent framework material in high-stress areas. Because of its low elastic modulus, PEKK was shown to produce minimal stresses at the terminal abutment of the framework, potentially allowing for shock absorption and stress dispersion. [13,14]

New generation CAD-CAM fiber-reinforced composite resins (FRCs) with high concentrations of multidirectional interlacing of high glass fibers have been used as implant-supported fixed partial denture frameworks for their high bending and compressive strength due to their reported shock-absorbing behavior, low elastic modulus, and high flexural strength. It also has outstanding biocompatibility with soft tissues and is lightweight. When compared to metal frameworks, fiber-reinforced composite resins perform better optically. [15,16]

Studies that compared reinforcing meshwork constructed from CAD/CAM-milled Pekkton (PEKK) and fiberglass-reinforced composite resin (FRC) and their effect on the fracture resistance of acrylic resin implant-retained overdentures are scarce, this study aimed to investigate the effect of these two materials on the fracture resistance of the acrylic resin of an implant-retained overdentures and compare it to metallic meshwork (CoCr) as (Control)

The study's null hypothesis was that there would be no significant difference between the three reinforcing meshwork materials as regards fracture resistance.

MATERIALS AND METHODS

Model construction and attachment abutment installation:

A 3D-printed study model was obtained for this study as follows: an educational gypsum cast of a completely edentulous mandible was scanned using a desktop scanner (Identica Hybrid – Medit – Korea). The STL file of the edentulous model was imported into CAD software (Exocad GmbH CAD/CAM software) to create and prepare two osteotomies in the virtual model at the canine areas bilaterally- (positions of teeth number 33 and 43). For the preparation of the osteotomies, the length and diameter of the implant analogues were measured beforehand, which are 4.5 mm in diameter and 12 mm in length, then two virtual cylinders were chosen with the same dimensions on the software. Moreover, a 2 mm cutback was made from the residual ridge area of the virtual model.

The virtual model was then printed without any hollowing using a digital light projection 3D printer (Creality Halot - China) using a resin specific for printing models (Proshape Dental Model - Turkey). Then, the two implant analogues (Neo Biotech - Korea) were secured in the prepared osteotomies onto which the ball abutments were secured. The silicon material was formed by the aid of a vacuum stent that was pressed on the original gypsum study model. Then, the silicon material (Gingifast – Zhermach - Italy) was injected after placing the stent on the 3D printed model, creating a 2 mm thickness of the silicon in resemblance to the soft tissue thickness. **(Fig. 1)**.

Later, scanning of the model and the ball abutments with its housings placed onto it was accomplished to obtain a virtual model over which the reinforcing meshwork was designed

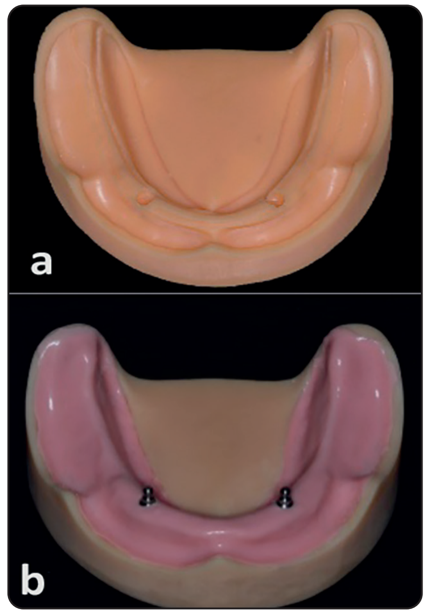

Fig. (1) 3D Printed cast a) showing the cutback, b) with ball abutments and gingival mask

Meshwork construction

The meshwork was virtually designed on the CAD software with three stoppers after adding virtual wax as a spacer of 0.5mm in thickness beneath the meshwork. The stoppers were located as two at the molar region and one at the anterior region, and then was exported to the CAM software to be either 3D printed or milled, as follows: **(Fig.2)**

- **Group I:** Five meshworks were milled from a blank of Pekkton (Cendres+Métaux – Switzerland) by a dental milling machine (K5 Milling Machine – VHF – Germany) with 1 mm thickness.
- **Group II:** Five meshworks were milled from a blank of fiberglass-reinforced composite resin *(TRILOR® Disks -Bioloren - Italy)* with 1 mm thickness.
- **Group III:** Five meshworks were 3D printed from a cobalt chromium alloy *(Scheftner dental alloys – Germany)* using a Laser Beam Powder Bed Fusion (PBF-LB) 3D printer (*VulcanTech GmbH- Germany)* with 0.5 mm thickness.

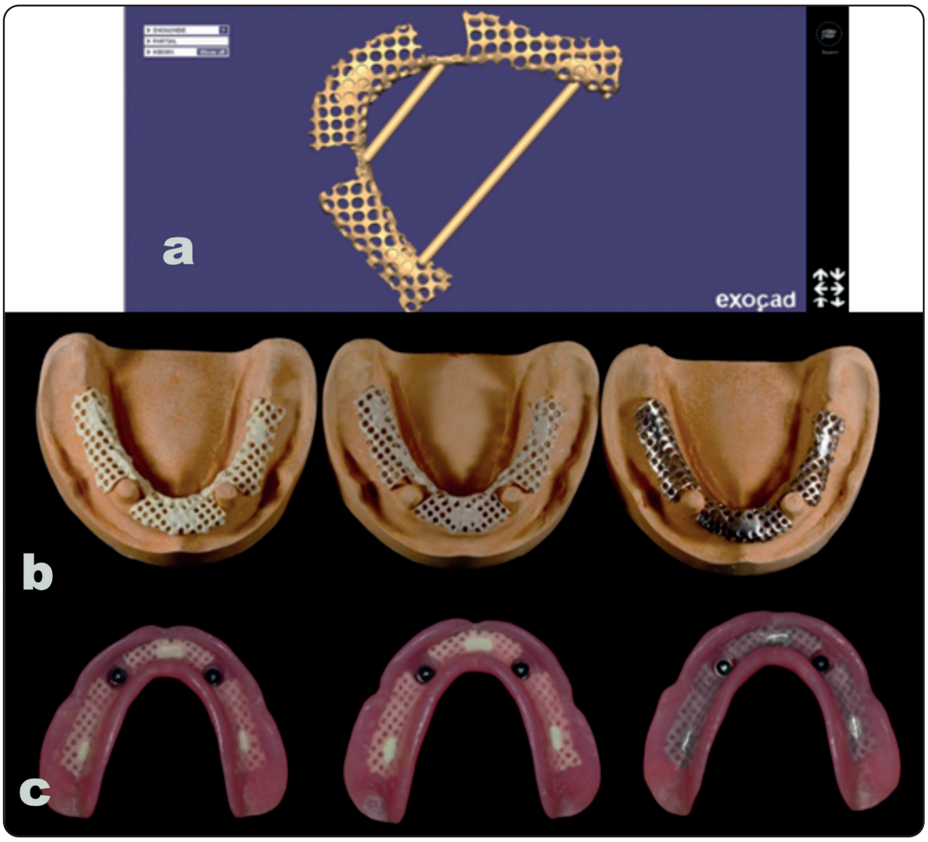

Fig. (2) a) Virtual design of the meshwork, b) meshworks after being CAD/CAM processed [FRC, PEKK and CoCr meshwork], c) Meshworks after being incorporated in the denture base [FRC, PEKK and CoCr meshwork]

Denture base construction:

The stone models on which the overdentures were built were created by duplicating the 3D-printed study model with the female housing connected to the ball abutments before overdenture processing. After teeth set-up, the flasking step of the mandibular implant-retained overdentures was followed, after wax elimination, the meshwork was placed on the cast and the acrylic resin was packed over it then the flask was closed and heat curing was achieved following the typical processing stages for the heat-cured acrylic resin overdenture (VertexTM-Dental B. V. Netherlands), finally, deflasking, finishing, and polishing was carried out. The fitting surface of the overdentures was then prepared at the sites opposite the ball abutments to create space for the metal housings, and then pick-up with self-cured acrylic resin (Acrostone-Cairo-Egypt) was performed.

Samples' testing:

Mechanical aging procedure:

The mechanical aging procedure was performed using programmable logic-controlled equipment; the newly developed four-station multimodal chewing simulator (ROBOTA- Egypt) integrated with a thermocyclic protocol operated on a servo motor (Model ACH-09075DC-T, AD-Tech Technology Co., Ltd., Germany). The ROBOTA chewing simulator has four chambers simulating vertical and horizontal movements simultaneously under thermodynamic conditions. Each of the chambers consists of an upper Jackob's chuck as a holder for the vertical screw that can be fixed to the load applicator.

Each sample was then placed on the corresponding cast while the Jakobe's chuck of the upper part of the machine was fixed through an inverted circular flat end-shaped plastic load applicator centrally positioned between the premolar-molar region posteriorly and two central incisor regions anteriorly to facilitate alignment with the loading axis of the machine and for proper load distribution. **(Fig. 3)**

The samples were fixed in a Teflon holder in the lower part of the simulator. A weight of 5 kg, comparable to 49 N of chewing force, was exerted. The test was repeated 75000 times to clinically simulate the 6-month chewing condition, according to previous studies.[17]

The test conditions were maintained at room temperature (23±2°C) and wet conditions (distilled water). The test was performed at specific parameters [vertical movement: 5 mm, rising speed: 90 mm/s, descending speed: 40 mm/s, cycle frequency 1.6 Hz – horizontal movement: 1 mm, forward speed: 90 mm/s, backward speed: 40 mm/s, weight per sample: 3 kg, torque; 2.4 N.m].

Fracture resistance test:

Loading was conducted using a universal testing machine. A vertical load was applied until the denture fracture was visible. Each cast with its denture was fixed to the lower fixed compartment of the testing machine (Model 3345; Instron Instruments Ltd., USA) with a load cell of 5 kN, and data were recorded using computer software (Bluehill Lite; Instron Instruments). To facilitate positioning with the loading axis of the machine and proper load distribution, samples were statically loaded (in compression manner) using a stainless-steel rod ended with a flat plate (40 mm width x 60 mm breadth X 10 mm thickness) attached to the upper movable compartment of the machine at a crosshead speed of 5mm/min until fracture occurred. The maximum failure load was recorded in Newtons (N) manifested with audible crack sound and a declined load–deflection curve recorded by Bluehill Lite computer software. **(Fig. 3).** Visual assessment of the fracture pattern was also carried

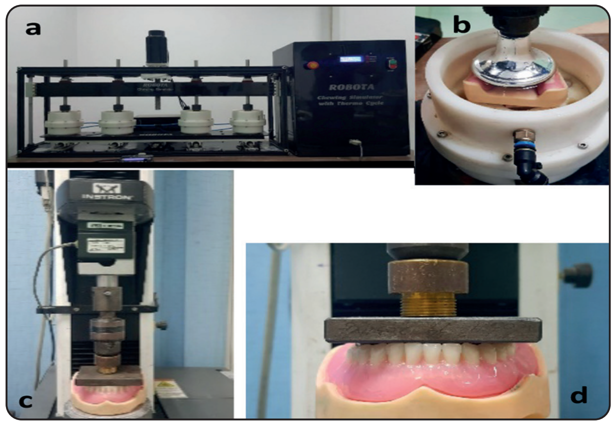

Fig. (3) a) ROBOTA chewing simulator, b) Cast inside the chewing simulator, c) Instron Device, d) Cast on Instron table

RESULTS

Statistical analysis was performed with SPSS 16® (Statistical Package for Scientific Studies), GraphPad Prism & Windows Excel. Exploration of the given data was performed using the Shapiro–Wilk test and Kolmogorov–Smirnov test for normality, which revealed that the data originated from normal data.

Accordingly, comparisons between 3 different groups were performed by One-Way ANOVA followed by Tukey's Post Hoc test for multiple comparisons. The significance level was set at p≤0.05.

Comparison between different groups:

The mean maximum failure load and standard deviation of all groups are presented in Table (1) and Figure (4). One-way ANOVA revealed a significant difference between the three groups (P=0.01). Tukey's post hoc test revealed that the mean maximum failure load was significantly lower in group 3 (3877±201.74) than in group 1 (4310±214.57) and group 2 (4261±218.41), with an insignificant difference between them.

TABLE (1) Mean maximum failure load (N) and standard deviation of all three groups and comparison between them:

	Mean	*Std. Deviation*	*P value (one-way ANOVA test)*
Group 1 (PEKK)	*4310.00 ᵃ*	*214.57*	
Group 2 (FRC)	*4261.00 ᵃ*	*218.41*	*0.01***
Group 3 (CoCr)	*3877.00 ᵇ*	*201.74*	

Means with different superscript letters were significantly different as P<0.05.
Means with the same superscript letters were insignificantly different as P>0.05.
****-: significantly different at P< 0.05.***

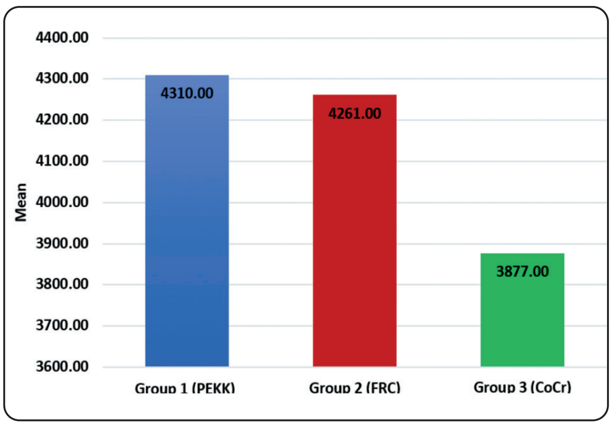

Fig. (4) Bar chart representing the mean maximum failure load (N) In the three groups.

The fracture pattern:

The visual assessment of the three groups revealed that: **(Fig.5)**

- In group 3 (CoCr) the cracks were several and were mainly seen in the midline, and areas corresponding to both housings from buccal and lingual sides.
- The same was seen with group 2 (FRC), al¬though, the number of cracks was minimal.
- In group 1 (PEKK), cracks were seen in the midline region in most of the samples.

Fig. (5) Fracture Pattern in a) midline in PEKK reinforced OD, b & c) CoCr reinforced OD, d) FRC reinforced OD

DISCUSSION

All manufacturers place a high priority on the fracture resistance of denture base materials since enhancing these features will allow the denture to bear more weight and prevent breakage that may result from abrupt falls or masticatory overload. Therefore, it was indicated that raising the denture thickness to a minimum of 2 mm would increase the denture base resistance to fracture. Furthermore, a method to strengthen the denture base and make it resistant to the pressures of the cantilever distal to the abutments of the two implant-retained overdentures by adding a metal framework was previously proposed. [18,19].

Polymers such as polyether-ketone-ketone (PEKK) and fiber-reinforced composites (FRCs) have been widely used in prosthetic dentistry for several reasons, most importantly their light weight and shock absorption capabilities due to their low modulus of elasticity compared to metal alloys [15]. In the current study, both polymers were used as an overdenture reinforcement material in addition to the use of cobalt-chromium alloy meshwork as a control, and the aim was to evaluate their effect in overdenture reinforcement.

For the manufacturing of the study models, a 3D printed cast was considered to allow for the virtual creation of the osteotomies in the cast to ensure complete parallelism between the two osteotomies for future placement of the implant analogues. In addition, a cutback of 2 mm was created at the crest, buccal and lingual faces to allow for placement of silicon as a soft tissue replica on the cast to mimic soft tissue resiliency. All meshworks were CAD/CAM manufactured, the FRC and PEKK meshworks were milled and the CoCr meshworks were 3D printed using the same STL file to maintain the same accuracy between them.

A chewing simulator was utilized in overdenture testing to simulate the oral environment as much as possible(20). To stimulate the biting force experienced by patients wearing opposing complete dentures, a weight of 5 kg—equivalent to 49 newtons of chewing force was applied(21). To stimulate six months of intraoral chewing, the test was repeated 75000 times(17). To replicate the characteristics of load application in the patient's mouth, the load was distributed to three points of contact: one anterior and two posterior points, using a flat plate load applicator.

The thickness of CoCr was 0.5 mm while that of FRC and PEKK was 1 mm and this is following other studies' recommendation,(22) as these polymers should not be less than 1mm in thickness otherwise it will affect their flexibility and will be more prone to fracture while in CoCr thickness should not be more than 0.5mm as it will affect the weight of the denture and will be uncomfortable to the patient, also, this might affect cases with inadequate interarch space. (23)

Another study was evaluating the effect of denture reinforcers in the fracture resistance of maxillary dentures using PEEK and metallic meshes, the study highlighted the importance of increasing the polymer meshwork thickness to be more than 0.7 mm and 0.9mm to enhance its effect as a denture reinforcer (24).

Based on the findings of this study, the results revealed that the mean value of maximum fracture resistance of the acrylic resin of the implant-retained overdentures was significantly the lowest in group 3 (3877±201.74), while group 1 and group 2 were significantly the highest (4310±214.57) and (4261±218.41), respectively, with an insignificant difference between them. Hence, the null hypothesis was partially accepted, as there was no significant difference between groups 1 and 2; however, there was a significant difference between group 3 and both groups 1 and 2.

A common site of cracks occurred at the midline in all groups, as the midline coincides with the notch opposite to the labial frenum and leading to insufficient thickness of acrylic resin at this area, thus it cannot withstand the forces and is subjected to fracture easily (25), moreover, this is the same reason of the cracks that occurred at the housings areas, because the acrylic resin is relieved to create space for the metal housings in preparation for pick-up leading to decreased thickness in the acrylic resin at this area. (26)

The pattern and number of cracks that occurred in each group could be attributed to the mechanical properties of each material regarding the modulus of elasticity. The modulus of elasticity of CoCr (27), FRC (16), PEKK (28) and the heat-cured acrylic resin is (29) (230, 26, 5, and 3 GPa, respectively).

By analyzing these numbers and comparing them with the current study findings, it could be described that the close values between the modulus of elasticity of the FRC, PEKK and the acrylic resin have had better load distribution for its flexibility within the internal structure of the overdenture when vertical load was applied by the testing machine; hence, this describes the insignificant difference between the values of both PEKK and FRC meshworks. On the other hand, the modulus of elasticity of CoCr is higher than that of the acrylic resin, which explains why cracks and fractures appeared at a significantly lower vertical load when applied to the overdentures. The large difference in the modulus of elasticity causes separation and failure between any two materials. (30)

The results came in similarity to another study that mentioned that fiber-reinforced composite materials have better fracture resistance and produce less stress concentration on the prosthetic base than metal reinforcement materials when compared in the case of implant-retained fixed partial dentures. (31)

In another study, PEKK and PEEK were compared as a framework in the case of implant-supported full-arch fixed prosthesis, and it was found that the superior shock absorbance of PEKK resulted in a lower stress concentration and better fracture resistance on the prosthetic screw and prosthetic base . This came in agreement with the current study findings (32)

New CAD/CAM materials, such as fiberglass-reinforced composite resin and Pekkton, are better alternatives to metallic meshworks as a reinforcement material in heat-cured acrylic resin implant-retained overdentures due to their light weight, resiliency, and shock absorption characteristics, and the provision of a metal-free restoration.

CONCLUSION

Within the limitations of the study, it could be concluded that implant-retained overdentures reinforced with CAD CAM meshworks made of fiberglass-reinforced composite resin (FRC) and Polyether-ketone-ketone (PEKK) seem to resist fracture better than those reinforced with CAD CAM meshworks made of cobalt-chromium alloys (CoCr).

RECOMMENDATIONS

1. Further clinical investigation is needed.
2. Further research is required to examine the potential of incorporating the CAD/CAM production of the used polymers into the full digital workflow of complete overdentures.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to Professor: Heba Shalaby – Professor of Dental Biomaterials – College of Oral and Dental Surgery - Misr University for Science and Technology, for her invaluable feedback and assistance throughout the study.

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