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IN VITRO COMPARISON BETWEEN SOME MECHANICAL PROPERTIES OF CAD/CAM POLYETHERETHERKETONE AND CONVENTIONAL COBALT CHROMIUM FRAMEWORKS IN REMOVABLE PARTIAL DENTURE

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ABSTRACT

Objective: To evaluate the fitting, flexure strength and clasp retentive force and deformation of RPD frameworks made from cobalt chromium and polyetheretherketone. **Materials and Methods:** Mandibular cast with a unilateral bounded saddle was fabricated, scaned and transferred to Exocad software. Twenty frameworks were fabricated and divided into two groups, group I for PEEK fabricated by CAD/CAM milling technique and group II for Co-Cr fabricated by conventional lost wax technique from 3-D printed resin pattern. Framework fitness was evaluated by replica technique and weighing by a digital analytical balance. Retention was measured by applying withdrawal force to frameworks by a universal testing machine. Deformation of clasps was evaluated by measuring the distance between 2 reference points on the tips of the retentive and reciprocal arms before and after repeated insertion/removal cycles by a chewing simulator. Biaxial flexure strength was determined using a piston-on-3points technique. **Results:** PEEK material group showed more adaptation than metal. For retention and deformation, metal group recorded higher retention mean value than PEEK but due to the higher deformation in metal there was no significant difference in retention after one year of use simulation. Metal group recorded higher flexure strength than PEEK. **Conclusions:** Within the limitations of this study, it could be concluded that milled PEEK frameworks have better tissue surface adaptation, totally acceptable retention forces reaches between 9 and 12N, and flexure strength between 137 and 144MPa. which is valid for clinical use.

KEY WORDS: CAD/CAM, PEEK, Removable Partial Denture

INTRODUCTION

Compared with more costly alternatives, removable partial dentures will likely remain an important treatment option and a significant need exists to advance the materials and technologies associated with these devices [(1)]. A complicated, error-prone and time-consuming process is the conventional manufacture of removable partial dentures (RPDs). A more effective method for manufacturing RPD frameworks is the use of computer-aided design and computer-aided manufacturing (CAD/CAM) techniques [(2)].

In terms of both data collection and manufacturing skills, CAD/CAM technology has advanced

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significantly since it was first introduced into the dental world. When sound instructions are followed, CAD/CAM is capable of providing well-fitting intra- and extra oral prostheses. The overall quality of dental prosthetics can be improved compared to the results obtained by conventional manufacturing methods, since CAD/CAM technology covers both surgical and prosthetic dental applications as well as fixed and removable prostheses [3,4].

CAD technology may either include additive manufacturing such as rapid prototyping or subtractive manufacturing such as computerized numerical control machining. By physically removing material from a blank by machining (cutting/milling) to leave the desired geometry, subtractive processing uses images from a digital file to create an object [5].

Spark erosion and milling are among the subtractive processing methods. Spark erosion can be described as a metal substratum process using continuous sparks to erode material according to the CAD data from a metal block under the necessary conditions. Milling techniques are diamond grinding and carbide milling which are now found together in chairside and inLab. CAD/CAM devices and laser milling are the latest transferred technology from manufacture industry for dental use. The accuracy of milling has shown to be within 10 μm[6-8].

An affordable and predictable treatment choice for the rehabilitation of partially edentulous patients has been traditional removable dental prostheses (RDP) with chrome cobalt frameworks and clasps. The disadvantages of metal RPD frameworks including the increased weight of the prosthesis, esthetically unacceptable display of clasps, the potential for metallic taste and allergic reactions have led to the use of a range of thermoplastic products in clinical practice [9,10]

Due to its lower Young's (elastic) modulus being similar to human bone, Polyetheretherketone (PEEK) has been used as a biomaterial in orthopedics for many years and has also been suggested for prosthodontic application due to its esthetic white colour and excellent mechanical properties [11,12].

By using the promising recently introduced PEEK-based polymer, the anti-allergic property, polishability, low plaque affinity, and wear resistance can be improved. PEEK RPD-frameworks include critical design features such as rests and indirect and direct retention components previously lacking in polymer-based prosthetics [13,14].

With a low melting temperature of 343°C, PEEK is a high performance thermoplastic polymer and can therefore be processed in different ways. One option is pressing the material in a dental technical laboratory with a special vacuum-pressing unit, PEEK can be used in granular form or as industrially pre-pressed pellets. Another option is the milling of preformed PEEK blanks industrially pressed under standardized parameters such as pressure, temperature and time using CAD/CAM technologies [15,16].

Little studies are carried out to evaluate the PEEK removable partial dentures, so this study was conducted to compare between some mechanical properties of the conventionally used chrome cobalt removable partial denture and the CAD/CAM PEEK.

MATERIALS AND METHODS

This is an in vitro Study conducted on a mandibular cast of high strength, minimal expansion dental stone (ADA type IV, Labstone, Egypt) with a unilateral saddle bounded by mesial and distal abutments covered by full metal crowns to resist abrasion during repeated insertion and removal of frameworks, with undercuts of 0.25mm and 0.50 mm on the buccal surface of premolar and molar abutments respectively.

Abutment teeth were sprayed with antiglare spray (Telescan spray white; DFS- Diamon GmbH, Riedenburg, Germany) and the cast was scanned using a 3D scanner (Medit T300; Korea) with an accuracy of 7 µm and imported into a digital inspection software (Exocad) as a standard tessellation language file (STL). Frameworks were divided into two groups, GI for PEEK and GII for Co-Cr, (10 each). Clasps were designed to have the same thickness and length (9mm in premolar and 13mm in molar) and subdivided into two subgroups (5 each): SGM engage the mesial abutment with 0.25mm undercut and SGD engage the distal abutment with 0.50mm undercut. Denture base minor connector was designed as a solid sheet without any holes and directly cover the residual ridge without any relief to facilitate measurement of fitness by replica technique. A small vertical rod (20 mm in length and 3 mm in diameter) was designed at the center of denture base minor connector (to produce a testing column of the framework).

Standard tesellation language file (STL), after framework designing, was exported to CAM software and converted to numerical computerized file (NC) format and exported to the firmware of the milling machine (Arum 5X-200, Doowon, Korea) where 10 PEEK frameworks were milled in a dry condition from PEEK blanks (98 mm diameter and 24 mm thick, Bredent, Germany). Resin (Phrozen grey resin, Taiwan) was placed in the tank of the printer (Phrozen shuffle, Taiwan), STL file was exported to CAM software and converted to slice file (SLC) format which was read by the frameware of the printer and 10 resin frameworks were printed. Frameworks were removed from the printer plate, rinsed with 95% alcohol and placed in a post curing unit (Bredent, Germany) for 50 minutes. Cobalt chromium frameworks were constructed from 3-D printed resin patterns by the conventional lost wax technique.

Twenty square bars were fabricated, for flexure strength testing, with 20mm in length and 3mm in diameter. Ten bars were made from PEEK by CAD/CAM and ten were made from cast Co-Cr.

Framework fitness:

Each framework was weighted by a digital analytical balance (Sortorious, Biopharma& Lab, Germany). A light-bodied silicone rubber impression material (Zhermack, Zetaplus, Italy) was mixed and placed on the fitting surface of frameworks, frameworks loaded with impression material were seated on the cast with a constant force of 40N using a universal tensometer (Lloyd instruments Ltd, England). Then frameworks were removed with impression material adhered to it. Frameworks with impression material trimmed to its borders were weighted again by digital analytical balance. The weight of impression material was calculated and used to represent the fit of the frameworks.

Retention and clasp deformity:

The distance between two reference points at retentive and reciprocal arms measured using a digital micrometer (Digimatic Micrometer, Mitotoyo, Japan) to the nearest 0.001mm. The force (N) needed to extract the frameworks was calculated by the universal testing machine applying the withdrawal force at 5 mm/min to it. A masticatory simulator (Robota, Germany) integrated with thermo-cyclic protocol operated on servo-motor was used to cycle the clasps on and off the metal crowns for 360, 720, 1440 and 2880 times, simulating the insertion and removal of RPD clasps during three months, six months, one year and two years, respectively. Each structure was mounted on the master cast and attached to the upper part of a vertical rod machine. Retention force and distance between the two reference points were measured after each cycling interval (Fug. 1) and recorded by the computer software (Bluehill, Instron instruments).

Flexure strength:

A piston-on-3-balls technique in a universal testing machine was used to assess the biaxial flexural strength (Lloyd instruments Ltd, England). With a 1.4 mm diameter steel cylinder, based on the

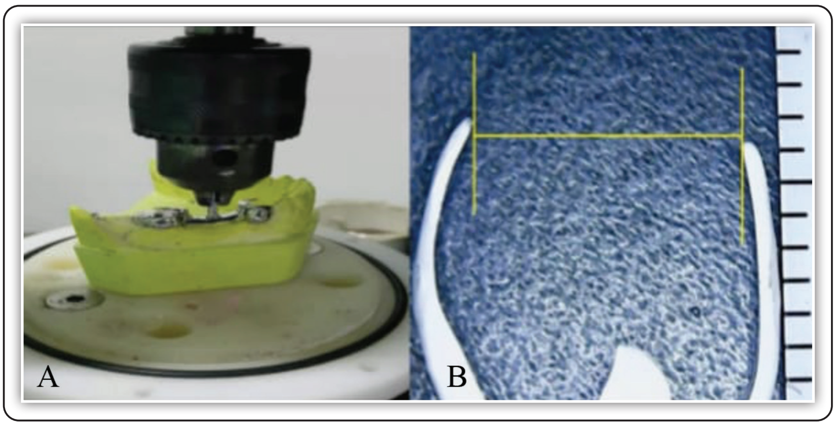

FIG (1) a) Clasp deformity by chewing simulator and b) image analysis software.

disk, flexural loading was applied at a crosshead speed of 0.5 mm/min until the fracture occurred and the force was registered. A piece of rubber dam was placed as a stress breaker between frameworks and the steel ball to remove any potential stress concentration during applying the load.

Data was obtained, tabulated and analyzed statistically using the software program Statistical Package for Social Sciences (SPSS) at a level of significance P<0.05. Student t-test was used to evaluate the differences between the two materials. One-way analysis of variance ANOVA was done between aging time subgroups for each group. Graph Pad Instat for Windows was used for statistical analysis.

RESULTS

1- Framework fitness:

It was found that metal group recorded higher means value of silicon impression material (0.077283± 0.00008 gr) than PEEK group (0.0582± 0.000116 gr). This indicate that PEEK material group showed more adaptation (Fig. 2). The t-test analysis showed significant difference between both groups at P ≤ 005.

2- Flexure strength (MPa):

It was found that metal group recorded higher flexure strength means value (1228.18± 37.275MPa) than PEEK group (140.8509±2.93556MPa). The t-test analysis showed significant difference between both groups at P ≤ 005 (table 1).

TABLE (1) Comparison of the framework fitness and flexure strength results between PEEK and metal groups.

	Framework fitness (gr)			Flexure strength (MPa)		
	PEEK	Metal	P value	PEEK	Metal	P value
Mean	0.0582	0.077283	<0.00001*	140.8509	1228.18	<0.0001*
S.D.	0.000116	0.00008		2.93556	37.27488	

S.D; standard deviation **; significant (P<0.05)*

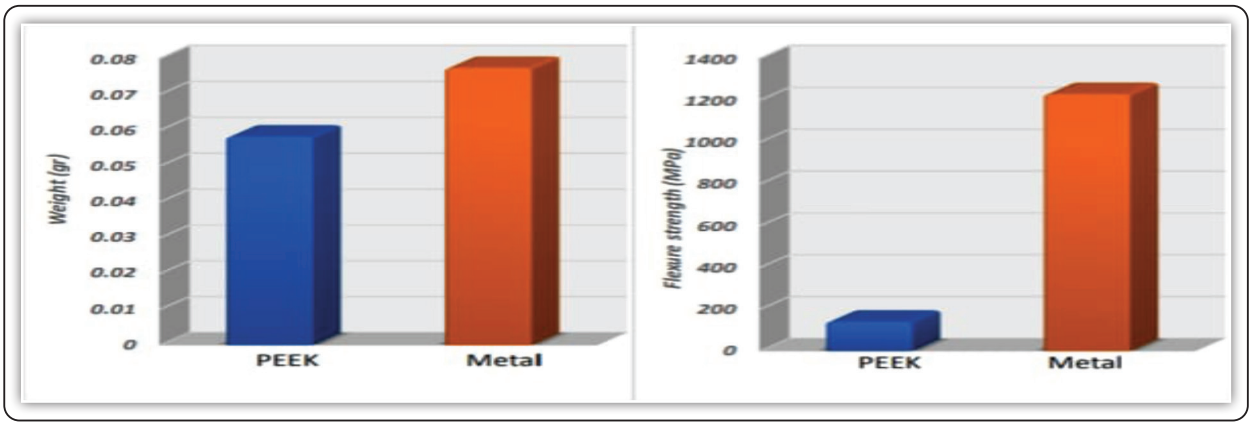

FIG (2) Column charts comparing adaptation and flexure strength mean values between PEEK and metal groups

3- Retention (N):

Mean retention values (N) are shown in table (2) and Fig. (3). At baseline it was found that metal group recorded higher retention means value (25.356± 3.09 N) than PEEK group (11.0518± 1.209 N). The t-test analysis showed significant difference between both groups. After 360 cycles (simulating three months of use) it was found that metal group recorded higher retention means value (18.4708± 4.05N) than PEEK group (7.3752±1.03N). The t-test analysis showed significant difference between both groups. After 720 cycles (simulating Six months of use) it was found that metal group recorded higher retention means value (6.7252± 3.531N) than PEEK group (3.3438±0.68N) (Fig. 3). The t-test analysis showed significant difference between both groups. After 1440 cycles (simulating one year of use) and after 2880 cycles (simulating twenty-four months of use) the t-test analysis showed that there was no significant difference between both groups. For both group; it was found that the retention decreased significantly with time as indicated by ANOVA test ($P \leq 0.05$) as shown in table (3).

TABLE (2) Comparison of the retention and deformity results between PEEK and metal groups.

		Retention (N)			Clasp deformity (mm)		
		PEEK	Metal	P value	PEEK	Metal	P value
At baseline	Mean	11.0518	25.356	<0.00001*			
	S.D.	1.209	3.09				
3 months	Mean	7.3752	18.4708	0.0007*	0.021	0.10425	0.05*
	S.D.	1.03	4.05		0.014	0.07	
6 months	Mean	3.3438	6.7252	0.048*	0.05875	0.07925	0.47 ns
	S.D.	0.68	3.531		0.025782	0.054687	
12 months	Mean	2.990275	3.138	0.079 ns	0.1445	0.09125	0.3771ns
	S.D.	0.342	0.6		0.086921	0.042452	
24 months	Mean	2.10335	2.3231	0.6239 ns	0.051	0.1605	0.174 ns
	S.D.	0.713	0.48		0.036722	0.159945	

**; significant (P<0.05)* *ns; non-significant (P>0.05)*

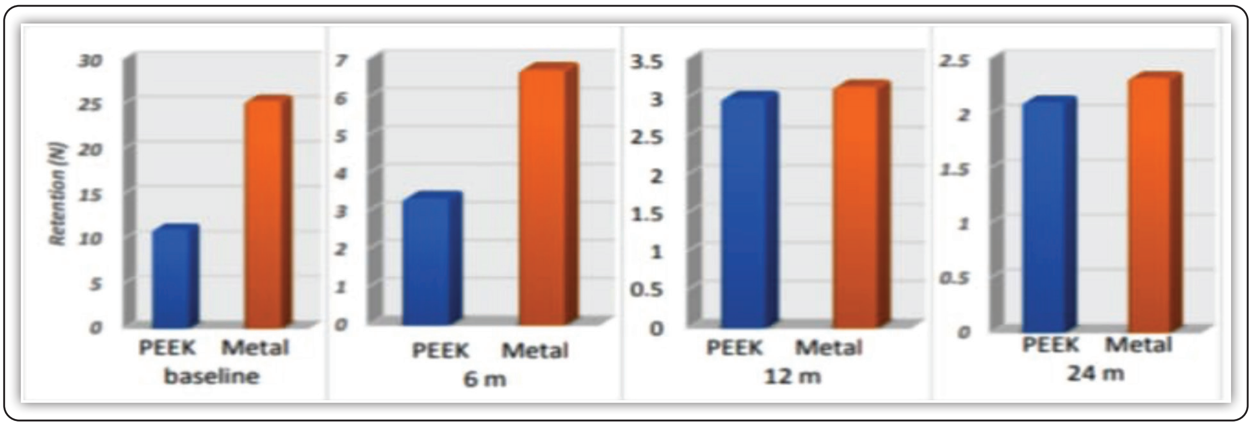

FIG (3) Column charts comparing retention mean values between PEEK and metal groups at baseline and after 6, 12 and 24 months of use simulation

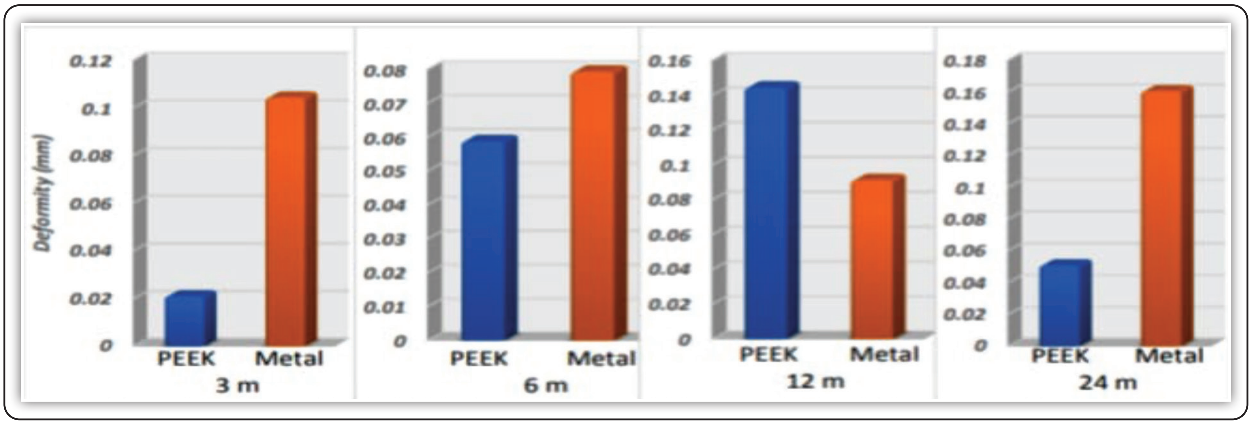

FIG (4) Column charts comparing deformity mean values between PEEK and metal groups after 3, 6, 12 and 24 months of use simulation

4- Clasp deformity (mm):

Mean clasp deformation values (mm) are shown in table (2) and Fig. (4). After 360 cycles (simulating three months of use) it was found that metal group recorded higher deformity means value (0.10425±0.07mm) than Peek group (0.021±0.014mm). The t-test analysis showed significant difference between both groups. After 720 cycles (simulating six months of use), after 1440 cycles (simulating twelve months of use) and after 2880 cycles (simulating twenty-four months of use) the t-test analysis showed that there was no significant difference between both groups. For PEEK group; it was found that the deformity changed significantly with time, while for metal group; the deformity did not change with time as indicated by ANOVA test ($P \leq 0.05$) as shown in table (3).

TABLE (3) Comparison of the retention and clasp deformity results as function of time simulation.

	Retention				Clasp deformation			
	PEEK		Metal		PEEK		Metal	
	Rank	ANOVA	Rank	ANOVA	Rank	ANOVA	Rank	ANOVA
At baseline	A		A					
3 months	B		B		C		A	
6 months	C	<0.0001*	C	<0.0001*	B	0.007*	A	0.5525 ns
12 months	C		D		A		A	
24 months	C		D		B		A	

*Different letters showing significant reduction of retention and deformation (p<0.05) *; significant (P<0.05) ns; non-significant (P>0.05)*

DISCUSSION

The demand for esthetic dental restorations has been increased due to an importance on physical appearance in modern society. For other framework elements, materials for clasps and frameworks of RPDs need to provide enough versatility for the clasps and rigidity. CoCr is therefore the most common alloy for RPD frameworks. Its bad esthetic appearance is the greatest drawback of Co-Cr clasps. Tooth-colored clasps made of thermoplastic resins were created to resolve these esthetic problems [(17)].

It was found that PEEK material group have a significantly better adaptation than metal group which recorded higher mean values of silicon impression material. These results may be explained by the findings of Hwang et al [(18)] that CAD/CAM reproduced the morphologic irregularity of the residual ridge.

Frank et al [(19)] suggested that the retention in RPD should be between 3 and 7.5N to protect against removal during the chewing of food. Helal et al [(20)] stated that the lowest acceptable retentive force for one clasp was approximately 1.6N.

Based on the results of the present investigation, the retention forces of the PEEK clasps show values clearly inferior to those of Co-Cr alloy, although clearly valid for their clinical use. Initially, it was found that metal group recorded significantly higher retention mean values ranged from 20N to 28N compared to PEEK group that recorded mean retention values ranged from 9N to 12N.

The variations found in the retention forces are possibly due to the different elasticity modules, according to Tannous et al [(21)]. Thermoplastic resins such as PEEK have a 4 GPa elasticity module very similar to 18 GPa cortical bone, so PEEK frameworks will minimize the stress transferred to the abutment tooth, whereas Cr-Co has a 230GPa elasticity module which is far higher.

Clasps undergo repeated bending caused by mastication, insertion, and removal of the RPD and therefore are vulnerable to the loss of retention. The retention of clasps usually changes after wearing the RPD for some time; thus, cyclic fatigue testing of clasps was also assessed in this study. It was found that metal group showed higher initial deformation than PEEK group. So that, after one year of use simulation (1440 cycles) there was no significant difference between both group retention. Retention decreased to about 3N for both groups. Unlike metal group which showed constant deformation after cycling (time of use simulation), the deformation of PEEK group showed significant reduction with time simulation.

These results come in agreement with a previous study by Peng et al [22]. He concluded that, relative to standard alloy clasps, PEEK clasps exert less stress on abutments, provide sufficient retention and meet esthetic requirements, suggesting that PEEK offers a promising alternative to traditional metal clasps. He also stated that both PEEK clasps and the conventional Co–Cr alloy clasps exhibited only slight deformation, and there was no significant difference between the two materials after fatigue testing.

It was found that PEEK material group flexure strength ranged from 173 MPa to 144 MPa that was clearly inferior to metal group flexure strength which ranged from 1182 MPa to 1273 MPa. However, Afify [5] in a previous study evaluated fracture resistance of non-metallic dentures/overdentures utilizing digital technology demonstrated that after 2 years of service a stable occlusion was confirmed with no clinical signs of occlusal wear or prosthesis fracture. He indicated that in the near future, CAD/CAM could well become the preferred method of manufacturing for most dental prostheses.

CONCLUSIONS

Taking into account the limitations of this study, it can be concluded that the use of milled PEEK non-metallic frameworks has better tissue surface adaptation, totally acceptable retention forces reaches between 9 and 12N, and flexure strength between 137 and 144MPa, which is valid for clinical use. However, it can be ensured that we can use PEEK frameworks for better esthetics than Co-Cr frameworks with the right clinical application. The study's restrictions because of its inclusion in an in vitro assay inside a rigid structure. The tooth is' cushioned' by the periodontal ligament in the oral cavity. Also, the manner in which the prostheses are placed and removed by the patient must be taken into account.

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