

Estimation of Fatigue Deformation for Polyetheretherketone (PEEK) and Cast Cobalt-Chromium Circumferential Clasps: A comparative study

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Abstract

Aims: This in-vitro study aimed to compare the fatigue deformation of Polyetheretherketone (PEEK) and Cobalt-Chromium (Co-Cr) clasps by mechanical cycling test simulating ten years of use. **Materials and Methods:** 72 clasps samples were fabricated on a standardized e-max upper right first premolar; it is divided into 24 Co-Cr clasps, and 48 PEEK clasps which were subdivided into two halves (2.4, and 3.00) mm width respectively. Each group was further subdivided (n=8 clasps) according to the amounts of abutment undercut (0.25, 0.50, and 0.75) mm respectively. Each clasp was digitally pictured by a microscope before cycling, and then mechanically cycled by a specifically designed insertion-removal apparatus for 15000 times on its specific abutment crown, and at the end of 15000 cycles, each clasp was digitally re-pictured, and the distance between the clasp tips in millimeter of the pre and post cycling pictures were measured with specific analyzing computer program. **Results:** The fatigue deformation of Co-Cr clasps was higher significantly than the PEEK clasps for the three undercuts. Deeper undercuts showed a significantly higher fatigue deformation for Co-Cr clasps but not significant for PEEK clasps. **Conclusion:** The fatigue deformation of PEEK clasps with both widths after 15000 cycles of insertion/removal was lower than Co-Cr clasps fatigue deformation.

الخلاصة

الاهداف: تهدف هذه الدراسة المختبرية الى مقارنة التشوه الناتج عن الاجهاد لمشبك الطقم الجزئي المعدني (كروم كوبالت) مع غير المعدني (بولي ايثر ايثر كيتون) بعد الاستخدام الافتراضي لمدة عشرة سنوات. **المواد وطرائق العمل:** تم تحضير (72) مشبك على الضاحك العلوي الايمن المصنع من الايماكس, قسمت العينات الى (24) مشبك كروم كوبالت, (48) مشبك بولي ايثرايثر كيتون والتي قسمت مناصفة بعرض (2,4, 3,00) مم على التوالي ومن ثم تم تقسيم كل مجموعة الى (8) مشبك حسب حجم منطقة الثبات على الضاحك (0,25, 0,50, 0,75) مم على التوالي. تم تصوير كل مشبك بالمجهر الرقمي ثم التدوير الميكانيكي لكل مشبك (15000 دورة) على الضاحك المخصص وبعدها اعادة التصوير. تم تحليل الصور باستخدام برنامج حاسوب متخصص لحساب المسافة بين نهايتي المشبك في الصورتين. **النتائج:** التشوه الاجهادي لمشابك الكروم كوبالت اكثر من تشوه مشابك البوايثرايثركيتون بدلالة احصائية. منطقة الثبات الاعمق اظهرت تشوها اجهاديا اكبر احصائيا لمشابك الكروم كوبالت ولكن دون دلالة احصائية بالنسبة لمشابك البولي ايثر ايثر كيتون. **الاستنتاجات:** التشوه الاجهادي لمشابك البولي ايثر ايثر كيتون (كلا العرضين) بعد الاستعمال ل 15000 دورة اقل من التشوه الاجهادي لمشابك الكروم كوبالت.

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INTRODUCTION

Many types of thermoplastic resins and cast metal alloys have been used to construct removable partial dentures (RPDs) ⁽¹⁾, but Co-Cr is the most popular ⁽²⁾. The popularity of Co-Cr alloys has been attributed to their low density (weight), high modulus of elasticity (stiffness), low material cost, greater stiffness, and lighter weight combined with suitable mechanical properties and resistance to tarnish ^(3,4). Many studies had been investigating cast Co-Cr clasps performance ^(5,6). These metal clasps were subjected to the deformation due to fatigue that has been happened due to repeated insertion and removal from the abutment teeth while thermoplastic resin clasps showed no or less deformation as had been reported ^(7,8). PEEK is a synthetic, tooth colored polymeric material with a modulus of elasticity similar to dentin, and non-allergic proposed to be used in dentistry ⁽⁹⁾. Little information are found about PEEK clasps and their fatigue deformation at long-term use.

The purpose of this study was to investigate the fatigue deformation of PEEK clasps with two widths retentive arms at three different undercuts after recurrent placement and removal on first upper premolar teeth and compared it to Co-Cr clasps as a control group. The null hypothesis was that there would be the difference in fatigue deformation between PEEK clasps and cast Co-Cr clasps.

MATERIALS AND METHODS

Natural beige PEEK (peekMED, Dental Direkt, Germany) and a conventional dental Co-Cr alloy (Co 63%; Cr 29%; Mo 6.5%; Magnum H60, MESA, Italy) were estimated in this study.

A. Abutment Fabrication

A synthetic acrylic resin first upper right premolar (Jining Xingxing Medical, China) was retained in a type IV stone matrix (Synarock XR, DFS Diamon, Germany). Surveying of the synthetic abutment was completed and guide planes were set to all clasp contacting surfaces by a milling machine (DENTAURUM GmbH & Co. KG, USA), to get a parallel path of insertion.

A composite rim (Tetric N-Ceram, Ivoclar Vivadent, Germany) was constructed to block the hindering undercuts on the cervical third of the crown from the mesio-buccal line angle all-around terminating at mesio-lingual line angle. This composite rim was used to determine the exact position, length, and end of the clasp parts.

An occlusal rest of 2.5mm length, 2.5mm width, and 2mm depth was prepared distally ⁽¹⁰⁾, a 0.25mm undercut (1) was set at the mesio-buccal surface, and impression of the abutment was recorded by a-silicone impression material (Elite P&P, Zhermack, Italy). The same method was used to produce 0.50mm (2), and 0.75mm (3) undercut abutment. The last two undercuts were chosen to imitate

the situation where the clasps should be placed closer to the gingival margin for esthetic ⁽¹¹⁾. The resulted in three stone models of abutment were forwarded to the dental laboratory who completed the processing of these models to produce an IPS e-max press abutment (Ivoclar Vivadent, Germany), in accordance with the manufacturer's instructions. Nakashima J. *et al.*, 2016 claimed that the IPS e-max had a similar abrasion to enamel ⁽¹²⁾.

B. Clasp Design and Fabrication

The resulted in IPS e-max abutment was surveyed to check the parallelism with the path of insertion and inspect the retentive undercuts. These abutments were scanned by 3D dental scanner (Dental Expert, Georgia), then a conventional circumferential clasp assembly were designed by Zirkozahn.modellier

software with a retentive arm of 1.5mm width and 1.0mm thickness and milled into a wax pattern by a 5-axis milling machine (imes-icore GmbH, Germany), then Co-Cr clasps were fabricated traditionally according to manufacture instructions.

Conventional PEEK clasps were designed with wider and thicker retentive and reciprocal arms to provide adequate retention ⁽¹⁾. The thickness of the retentive arm was 1.5mm with two widths; first was fine (f) of 2.4mm at the origin, 1.8mm at the middle, and 1.2mm at the tip of the arm; while the second was wider (w) with 3.00mm at the origin, 2.3 at the middle, and 1.5mm at the tip of the arm. The reciprocal arm was of 1.5mm thickness and 1.5mm width for all clasps ⁽¹⁾. These two designs were directly milled from PEEK discs by a 5-axis milling machine (Figure 1).

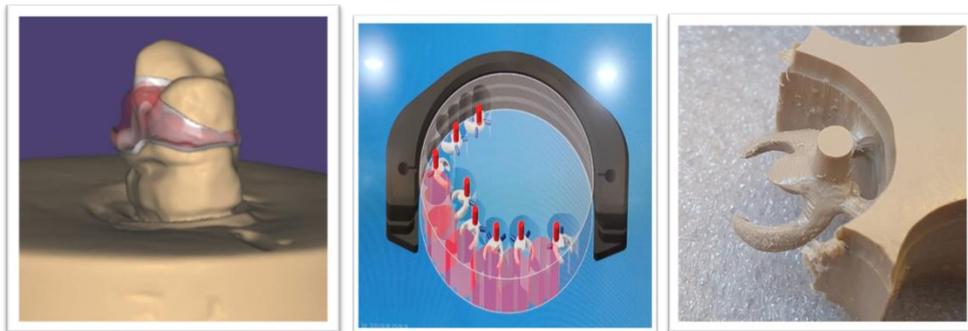


Figure (1): Steps of The Clasp Design and Fabrication

A total of 72 clasps were produced, forming nine groups, including 3 control groups of Co-Cr for 3 amount of undercut (Co-Cr1, Co-Cr2, and Co-Cr3), and 6 study groups of PEEK, 3 for each width

for 3 amount of undercut (Pf1, Pf2, Pf3, Pw1, Pw2, and Pw3)

C. Mechanical Cycling

A modified jelenko surveyor (QD, England) was used as a chewing simulator machine. The e-max tooth with its resin base was fixed to the table of the surveyor in parallelism to the path of insertion, and the clasp was retained in the locking device of the surveying beam. The clasp was removed and reinserted at a speed of 10mm/s simulating the placement and removal of RPD by a patient ⁽¹³⁾. The study conditions were performed in a dry environment and at room temperature (25°C).

D. Fatigue Deformation Measurements

A digital microscope (Koolertron, China) at a magnification power of 120 times was used to take a photo for each

clasp individually which is retained on an a-silicone impression material placed in a round small dish of 5cm diameter and 1cm thickness. Mechanical cycling for each clasps 15000 times, matching the simulated insertion and removal of RPD over ten years, supposing that the patient would execute four complete cycles per day ^(11, 14). The clasps were pictured again under the same position. The digital photos (Figure 2) of the clasps were tested by Image J program to investigate the distance in millimeters between the tips of the retentive and reciprocal arms of each clasp ^(7, 8).



Figure (2): Magnified Picture Of The Clasps Under Digital Microscope With Digital Caliper For Distance Analysis.

RESULTS

The mean fatigue deformation measured in millimetre (mm), standard deviation from zero to tenth cycles for nine groups of both clasps' materials is analyzed using the SPSS program

(version19). Table (1) illustrated means in all groups with the higher values in the Co-Cr control group at all amounts of the undercut.

Table (1): Means and Standard Deviations of Clasps Fatigue Deformation (Mm) At the End of Ten Mechanical Cycles of Co-Cr and PEEK Clasps with Three Undercuts

Material	Undercut(mm)	N	Mean(mm) ± SD
Co-Cr Control groups	0.25	8	0.315±0.0667*
	0.50	8	0.371±0.0864*
	0.75	8	0.635±0.2162*
PEEK, fine retentive arm Pf	0.25	8	0.122±0.1025
	0.50	8	0.153±0.0602
	0.75	8	0.165±0.0523
PEEK, wide retentive arm Pw	0.25	8	0.168±0.0601
	0.50	8	0.205±0.1024*
	0.75	8	0.292±0.1568*

*significant difference from the control groups, N: number of the samples, SD: standard deviation.

Table (2) shows one-way analysis of variance (ANOVA) for comparison of the fatigue deformation of Co-Cr and PEEK clasps at each abutment undercut. Results showed that there was a significant difference of retentive force of all groups

at $p \leq 0.01$ with means of Co-Cr clasps at each abutment undercut significantly bigger than PEEK clasps with both width of the retentive arm. However, Abutment undercut showed a significant effect on Co-Cr clasps deformation, and a non-significant effect on PEEK clasps.

Table (2): One Way Analysis Of Variance (ANOVA) of the Fatigue Deformation (Mm) For Three Undercuts Groups Using Co-Cr and PEEK Clasps.

Undercut type	Source of variance	Sum of Squares	df	Mean Square	F	Sig.
Undercut 0.25	Between Groups	0.162	2	0.081	13.045	0.000*
	Within Groups	0.130	21	0.006		
	Total	0.292	23			
Undercut 0.50	Between Groups	0.207	2	0.103	14.377	0.000*
	Within Groups	0.151	21	0.007		
	Total	0.358	23			
Undercut 0.75	Between Groups	0.945	2	0.473	19.132	0.000*
	Within Groups	0.519	21	0.025		
	Total	1.464	23			

df: degree of freedom, * Highly significant difference existed at $p \leq 0.01$.

DISCUSSION

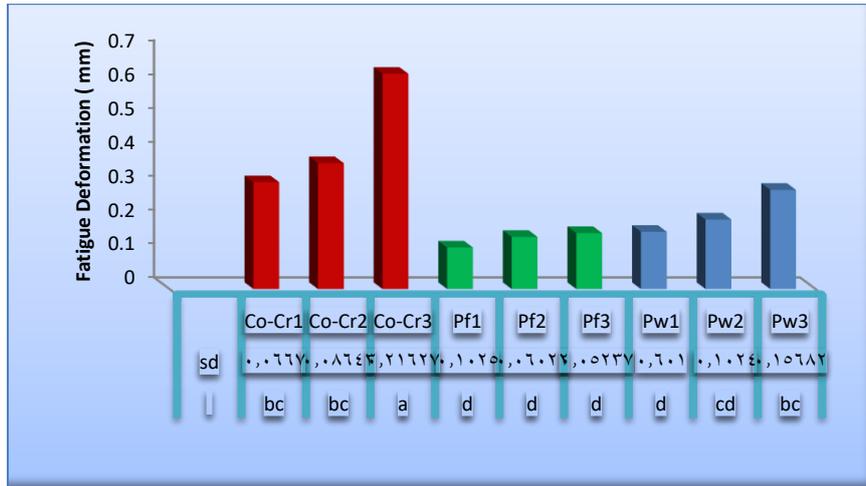
The results of the present study showed that the fatigue deformation was

higher in Co-Cr clasps than PEEK clasps. On the other side, the fatigue deflection for PEEK clasps (both widths) showed no

significant difference. So, the null hypothesis that there would be a difference in fatigue deformation between PEEK clasps and cast Co-Cr clasps was accepted.

Fatigue deformation of the clasp affected by the material from which it is

constructed, design of the clasp, loading orientation ⁽¹⁵⁾, amount of deflection (undercut measurement) and the number of deflections which represent repeated insertion, and removal of the clasp ^(2, 16).



*Duncan's Multiple Range Tests: Means with different letters are statically significant at $p \leq 0.01$.

Figure (3): Mean \pm Standard deviation and Duncan's multiple range tests for Clasps Deformation for Nine Groups

The cast metal clasp is anticipated to be used for a long period with 0.25mm undercut, otherwise plastic distortion of the clasp or periodontal ligament problem of the abutment tooth will occur with deeper undercuts because the metal will work closer to its yield stress ⁽¹⁷⁾ and surpass its proportional limit^(5,6). In the present study the Co-Cr clasps at 0.50 and 0.75mm undercuts were significantly deformed more than 0.25mm undercut (table 1).

The results of the present study showed that the PEEK clasps of both widths had significantly lower fatigue deformation than Co-Cr clasps at each undercut separately (0.25, 0.50, and

0.75mm). This result agreed with the result of Marie A. et al., 2019 ⁽¹³⁾ which may be attributed to the PEEK resiliency, so it can neglect the forces of elastic deformation without distortion while Co-Cr is not resilient enough to neglect the distortion forces ⁽¹⁸⁾.

A past study of Co-Cr clasp and acetal resin clasp proved bigger distortion of resin clasps after three years of simulated use ⁽¹⁹⁾, while Arda T. and Arikan A., 2005 in a similar study claimed that Co-Cr clasp distorted significantly in contrast to acetal resin clasp that was not distorted and presumed that the whole resin clasps were twisted during removal

and insertion neglecting the probability of distortion⁽⁷⁾.

Other authors approved that there was a significant fatigue deformation for Co-Cr, and acetal resin clasps in 0.50mm undercut^(8, 20), while Meenakashi A. et al., 2016 stated that Co-Cr clasps distorted more than acetal resin but without significance⁽²¹⁾.

CONCLUSSION

The PEEK clasps were not deformed even in deep undercuts (0.50, 0.75mm), and this encourages its use in case of unfavorable undercut instead of Co-Cr clasps. Co-Cr clasps deformed highly, so it will need to be adjusted frequently to increase adaptation and retention which make it subjected to fracture.

Limitation of the study:

The limitation of the present study is that it was accomplished in a mere rigid system, and fatigue deformation was inspected as a function for the mechanical factor only (clasp), while the influence of soft tissue, periodontal ligament, movement during functioning (mastication), physiological, physical, and muscular factors was not studied.

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