EGYPTIAN DENTAL JOURNAL
www.eda-egypt.org
Vol. 70, 2549:2557, July, 2024
Print ISSN 0070-9484 • Online ISSN 2090-2360
Fixed Prosthodontics and Dental Materials
Submit Date : 01-04-2024 • Accept Date : 14-05-2024 • Available online: 10-07-2024 • DOI : 10.21608/EDJ.2024.281044.2996

# RETENTION AND SURFACE ROUGHNESS OF POLY ETHER KETONE KETONE (PEKK) VS. ACETAL RESIN FRAMEWORK IN KENNEDY CLASS IV REMOVABLE PARTIAL DENTURES: AN IN VITRO STUDY

Mohamed Abdel Hakim Abdel Aal*,, Iman A El-Asfahani**, Tarek AbdAllah Mahmoud*** *and* Doaa Tawfik hassan****

## *ABSTRACT*

**Aim of study**: to evaluate retention & surface roughness of PEKK & Acetal Resin frameworks in Kennedy class IV RPD.

**Materials and methods:** Twelve partial denture frameworks were constructed for this study, acrylic resin (AR) model of Kennedy class IV maxillary arch was constructed & RPD design was established. Abutment preparations were made; digital scanning & RPD framework was virtually designed in 3D format. The STL file was transferred to 5-axis milling machine for milling the PEKK blanks producing PEKK frameworks. For acetal resin frameworks, the STL file was used to print an AR 3D printed framework which was flasked, after which the acetal resin frameworks were produced by injection molding technique. A Universal testing machine was used to evaluate retention of RPD frameworks at different simulated time intervals. The surface roughness of the RPD frameworks were evaluated using 3D optic profilometer at a fixed selected area in all frameworks.

**Results:** The PEKK partial denture framework showed statistically insignificant higher mean values compared to acetal resin at baseline, 3 & 6 months. A significant difference was noticed at the 1, 1.5, 2, 2.5 & 3 year cycles. There was an insignificant difference between the surface roughness of the PEKK & acetal resin frameworks.

**Conclusion:** Within the limitations of this study, it can be concluded that the PEKK may provide significantly better retention compared to acetal resin in Kennedy Class IV partial denture frameworks. However, both materials showed an insignificant difference regarding their surface roughness.

**KEYWORDS:** Retention, Surface roughness, CAD/CAM, Partial denture framework.

* Associate Professor in Prosthodontics Department, Faculty of Dentistry, Beni-Suef University
** Associate Professor, Prosthodontics Department, Faculty Of Dentistry, Minia University, Egypt
*** Lecturer, Removable Prosthodontics Department, Faculty of Dentistry, Modern University for Technology and Information (MTI).
**** Lecturer , Prosthodontics Department , Faculty of Dentistry, Minia University

## INTRODUCTION

Partially edentulous patients with long edentulous spans are not indicated for fixed prosthesis, whereby removable partial dentures (RPDs) are one of the treatment modalities for such clinical situations for restoring lost hard and soft tissues as well as the need for esthetic support of the oro-facial structures. [1]

The most versatile and cost-effective definitive RPDs are those fabricated from cobalt chromium alloys however, the unacceptable esthetics from the metallic display of the clasps, heavy weight, metallic taste possibility and allergic reactions to the metallic prosthesis are drawbacks for such prosthesis that led to replacing the metal by using thermoplastic materials such as acetal resin and nylon.[2]

Retention through direct retainers is considered as a major factor in determining the success of removable partial dentures. Retention capability depends on the mechanical properties of clasp material. Although Cr-Co clasps are widely used, they possess few drawbacks like failure of retentive arms under stress, frequency of repairs and esthetics. [3]

Multiple thermoplastic resins have been developed to achieve the required mechanical and esthetic requirements as a removable partial denture framework and clasp material. [4]

Thermoplastic acetal resins are unbreakable, use quick injection method and develops tooth-colored retainers providing optimal esthetics by eliminating metallic display. It is flexible having low modulus of elasticity that leads to decrease the stresses on the abutment teeth, [5] and don't need periodic adjustment [6] as well as it doesn't adhere to conventional acrylic resin [7]; the retentive force of these clasps is somewhat more prominent than the normal retentive force. Different clasps were inspected for this speculation with a specific end goal to examine their retentive force. [8]

The poly ether ketone ketone (PEKK) and poly ether ether ketone (PEEK) are the two most well-known of the poly aryl ether ketone (PAEK) family; PEKK is a new evolving polymeric material. PEKK biomaterials is an elastic material with good shock absorbance and fracture resistance and presents ultra-high performance among all thermoplastic composites for excellent mechanical strength, chemical resistance, and high thermal stability. Recently, PEKK is used in removable partial denture (RPD) as dental clasps and frameworks using digital technology. [9] PEKK clasps can be used to provide retention for a longer duration and can also be used as inserts in the removable partial denture.

The retention of the prosthesis is an extremely important aspect establishing a valuable partial denture treatment and higher patient's satisfaction. Lower partial denture retention force causes inferior denture stability during mastication and consequently reducing masticatory efficacy and performance. [10, 11]

Surface roughness of denture base materials have a direct effect on accumulation of plaque , adherence of Candida Albicans.[12] Materials with high surface roughness act as a reservoir for harboring microorganisms. This allows denture stomatitis to occur, halitosis and affects the mouth and denture hygiene. Moreover, reduced surface roughness and smooth denture surfaces provides good esthetics, reduces denture staining and enhances patient comfort, therefore denture base materials surface roughness investigation is of great concern. [13,14] Accordingly, the research question was the material of partial denture whether acetal resin or PEKK can influence the retention and surface roughness of partial dentures in maxillary Kennedy Class IV cases or not. The null hypothesis was that there would be no significant difference in retention and surface roughness of Acetal resin versus PEKK partial denture frameworks in Kennedy Class IV cases.

## MATERIALS AND METHODS

The least sample size was calculated based on an earlier study which aimed to evaluate the retention of acetal resin and cobalt-chromium removable partial denture clasp.[15] The sample size was calculated to detect the difference in retentive force among the three studied groups. Based on the latter study results, adopting a power of 80% to detect a standardized effect size in retention force (the primary outcome) of 0.874, and level of significance 5% ($\alpha$ error accepted =0.05), the minimum required sample size was found to six partial denture frameworks for each group. Therefore, the total sample size was 12 partial denture frameworks.

An acrylic resin model was made by duplicating a maxillary Kennedy class IV stone cast using heat cured acrylic resin (Acrostone, Egypt). The model was accurately replicating the anatomical features of teeth and edentulous span, the base of the acrylic resin model was trimmed parallel to the occlusal plane. Surveying the acrylic model by a dental surveyor (Ney surveyor, USA) was done at zero tilt and the removable partial denture design was established.

Rest seats preparation was made on the occluso-mesial surfaces of first premolars bilaterally to receive a supporting saucer shaped rest; another rest seat preparation was made on the occluso-distal surface of first molars as well as on the occluso-mesial surfaces of the second molars bilaterally to receive a double Aker's clasp with an antero-posterior palatal strap as a major connector.

The acrylic resin model was digitally scanned (smart optics, Germany) after spraying the model by the scanning spray. Followed by digital surveying including marking the survey line, undercut depth identification to be used for retention (utilizing 0.50 mm undercut depth), path of insertion selection, blocking undesirable undercuts and digitally creating the double Aker`s clasps with retentive tip thickness of 1.5 mm. Finally the framework was virtually produced in a 3D format by using the Exocad digital software of the CAD CAM system. **Fig (1)**

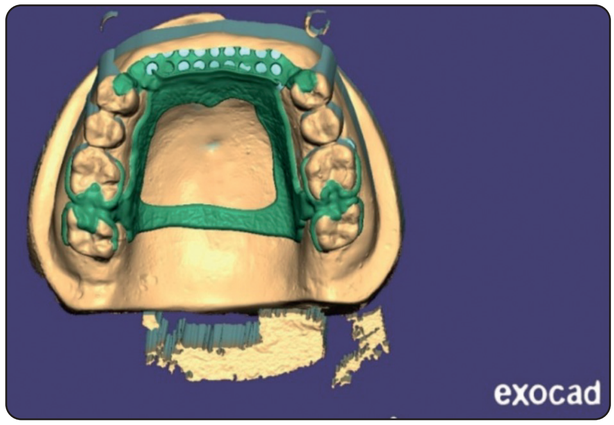

Fig (1) Virtual Framework Digitally Produced

### Fabrication of the PEKK framework

The virtual 3D designed framework standard tessellation language (STL) file was transferred to a 5-axis milling machine (VULCANTECH VM120,Germany) for milling of the PEKK blanks (Pekkton ivory; Cendres+Métaux SA, Switzerland) producing the PEKK frameworks. **Fig (2)**

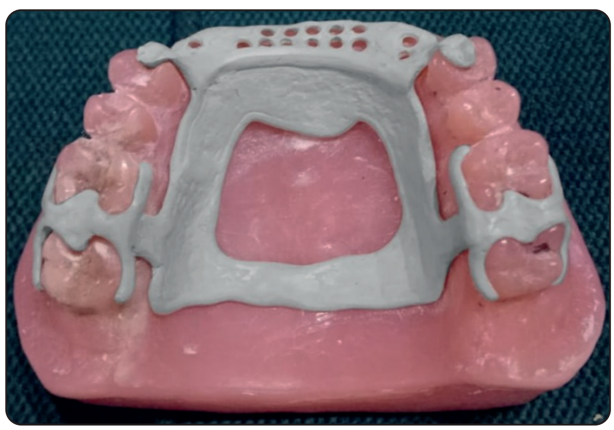

Fig (2) Milled PEKK Framework

### Fabrication of the acetal resin frameworks

The virtual 3D designed framework was used to print acrylic resin 3D printed frameworks (IFUN Dental Resin, lancer 3D) **Fig (3)**

Fig (3): 3D Printed Acrylic Resin Framework

The 3D printed acrylic resin frameworks were flasked with type IV hard dental stone. After setting; the flasks were opened and the acrylic resin frameworks were removed.

Acetal resin (Biodentaplast Cartridges Acetal resin Bredent, GmbH, Germany) was prepared according to manufacturer's instructions, heated, and plasticized then injected by the injection machine (Thermopress 400 injection molding system; Bredent, Germany) into the mold (injection molding technique); the acetal was cured at 215°c for 25 minutes with an injection pressure of 4 bar. After curing, the frameworks were deflasked, finished and polished using finishing burs and pumice at low speed until buffed to fine luster. **Fig (4)**

Fig (4) Acetal Resin Framework

**Retention measurement**

***Geometric center determination***

Three points were marked on the cast, one point at each tuberosity and one at the incisive papillae. A triangular card board was made connecting the three marked points with the triangle base between the tuberosity marks and its apex at the incisive papillae. Three lines were drawn on the card board intersecting each angle of the triangle, the point at which the three lines meet is the geometric center of the arch.

Three holes were prepared away from the palatal margins by 2-3 mm in the framework to allow passage of metal wires (1mm diameter) through it, the wires were passed away from the occlusal plane and are collected together to a ring at the marked geometric center from which the hook of the universal testing machine (UTM) (LLOYD LR 5K England) was attached and a tensile load at crosshead speed of 5 mm/min was applied until it stops automatically **Fig (5)**. The procedure was repeated 5 times for each framework and readings of the load required to totally dislodge sample was recorded in Newton.

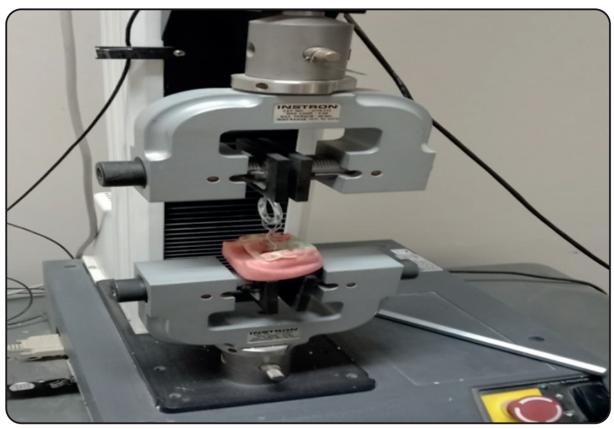


Fig (5) Retention measured by the universal testing machine

The Retention of each design was measured at base line and simulation of 3 months, 6 months, one year, 1.5 years, 2 years, 2.5 years and 3 years, each time interval was simulated by insertion and

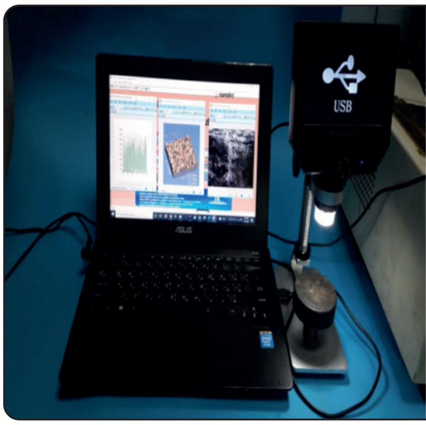


Fig (6) 3D Optic Profilemeter

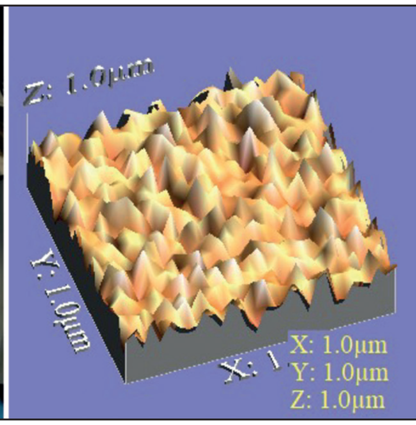


Fig (7) Acetal resin surface roughness

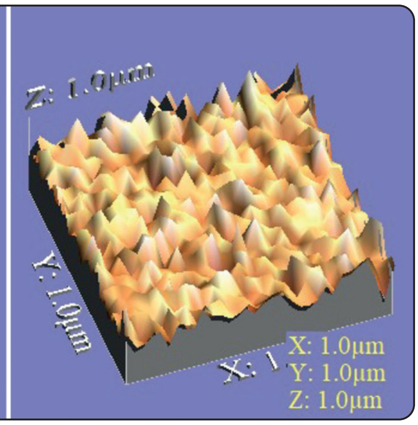


Fig (8) PEKK surface roughness

removal of the framework as per day 3 times and each period was measured 5 times and the average was calculated.

### *Surface roughness measurement*

The surface roughness of the frameworks was measured using the 3D optic profilometer (Koolertron/CD Digital microscope, Hong Kong), a fixed area in all frameworks were selected for measuring the surface roughness, measurement was taken three times. **Fig. (6-8)** .

The average of the recorded retention measurement and surface roughness was calculated, tabulated, and statistically analyzed.

## RESULTS

Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp. Data was explored for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests. Retention data showed normal distribution. Data was presented as mean and standard deviation (SD). Paired t-test was used to compare between tested groups and repeated measures ANOVA was used to compare cycles followed by multiple comparisons with Bonferroni adjustment. One-Way ANOVA used to compare between tested groups for roughness test. The significance level was set at $P \leq 0.05$.

### Retention

As shown in table (1) & fig. (9), although PEKK showed the higher retention values compared to acetal resin in all cycles, there was an insignificant difference between PEKK and acetal Resin at baseline, 3 months, and 6 months. A significant difference between the PEKK and acetal group was found at 1, 1.5, 2, 2.5 and 3 year cycles. Within the acetal resin group, retention decreased significantly after 2.5 and 3 years, while for PEKK; all cycles showed insignificant difference except at the 3year cycles a significant loss of retention occurred.

TABLE (1) Retention force (Mean & SD) of PEKK and Acetal resin groups measured in newton

| Cycles | PEKK | | Acetal resin | | p-value |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | |
| **Baseline** | $18.07^{a}$ | 1.78 | $17.74^{b}$ | 2.12 | 0.06 |
| **3 Months** | $16.76^{a}$ | 2.51 | $15.26^{c}$ | 0.95 | 0.31 |
| **6 Months** | $16.43^{a}$ | 2.01 | $13.61^{d}$ | 0.78 | 0.07 |
| **1 Year** | $14.61^{a}$ | 1.59 | $11.27^{e}$ | 1.57 | <0.001* |
| **1.5 Year** | $13.18^{a}$ | 0.65 | $10.68^{f}$ | 0.95 | <0.001* |
| **2 Years** | $12.37^{a}$ | 0.82 | $9.68^{g}$ | 1.25 | <0.001* |
| **2.5 Years** | $11.08^{a}$ | 0.94 | $8.42^{h}$ | 1.02 | <0.001* |
| **3 Years** | $7.78^{i}$ | 0.59 | $5.57^{j}$ | 0.93 | <0.001* |

***Different superscript letters within each column indicates significant difference,* p-value ≤ 0.05 is considered significant***

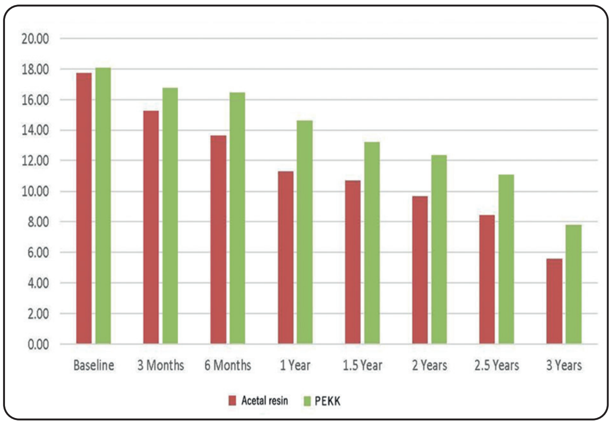


Fig. (9) Bar chart showing the mean Retention for the tested groups

## Surface Roughness:

As shown in table (2) & fig (10), there was an insignificant difference between the surface roughness of the PEKK and acetal resin groups (p> 0.05)

TABLE (2) Mean and SD for surface roughness for different tested groups measured in $\mu$m

| | PEKK | | Acetal resin | | p-value |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | |
| **Surface roughness** | 0.2926 | 0.0028 | 0.2870 | 0.0151 | 0.612 NS |

***-NS= non-significant***

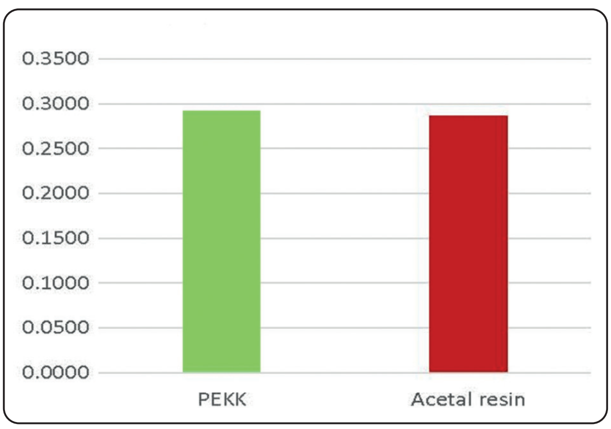


Fig (10) Bar chart showing the mean surface roughness for the PEKK and Acetal resin groups.

## DISCUSSION

Function, accuracy and esthetics of the dental prosthesis have been improved by recent technology of digital dentistry such as the three dimensions scanning and printing, computer aided design and computer aided manufacturing. Thus, advocate for more researches on the milled and additive manufacturing of thermoplastic RPDs material. [16]

The real advantages of the thermoplastic materials includes the homogeneity of the material, simple process of manufacturing, reproducible restoration as the STL file can produce the same design multiple times with accuracy and more time saving in addition to the improved reliability and stability of the RPDs milled from pressed blanks. [17] Thus, in the present study Acetal resin and PEKK RPDs fabricated with the digital manner were evaluated.

The thermoplastic flexible RPDs material evaluated in the present study had the same specific dimensions for all groups which agree with previous studies. The studies clarified that the clasps fabricated from thermoplastic resin must be designed with minimum thickness of 1.5 mm to overcome the low rigidity of the resin and engaging deeper undercut ranging from 0.50 mm or 0.75 mm to provide acceptable retention. [18-20]

The retention, stability and biomechanical behavior of the RPD are mandatory required for successful treatment. [16, 21]

The retention of the RPD depends on material of the clasp, its modulus of elasticity and length in addition to the used undercut depth of the abutment teeth. Based on the previous studies the clasp was designed to engage more than 0.25 mm undercut with average length of 15 mm. [21,22]

Retentive clasp tip utilize an undercut depth of 0.50 mm was selected based on the previous studies which proved the significant difference of retention value between 0.25 mm undercut and the more deeper undercuts. The results of the previous researches revealed also that there were no significant difference between using 0.50 mm or 0.75 mm undercuts. [23]

The undercut depth of 0.50mm was recommended as it provides acceptable clinical retentive values, utilizing deeper undercut, engage the abutment tooth near the marginal gingiva and improve the esthetic outcomes. [18, 24]

In the present study, the retentive forces recorded in PEKK and Acetal groups showed significant higher values than results recorded in earlier studies that use the same materials and measure within the same time intervals, [16, 25] this may be attributed to that earlier studies evaluated the effect of direct retainer or frameworks utilizing one tooth only in each side for retention while in the present study the measured retention considered a summation of retentive force of bilaterally double Aker`s direct retainers, frictional resistance to removal provided by the guiding planes contacting RPD components during removal (minor connectors and proximal plates).

The retentive force values of PEKK direct retainer in the present study showed higher values than Acetal clasp retainer, which agree with previous study results, which demonstrate the least forces of retention for Acetal followed by PEEK and studies which evaluate PEKK direct retainer groups showed the higher values of retentive forces.[22, 26-28]

Moreover the superiority in the retentive values demonstrated by the difference of elastic modulus where the higher modulus denotes less flexibility thus improving retention. The modulus of elasticity represented in Giga Pascal, showed extremely higher values for Cr-Co RPDs followed by PEKK, PEEK and finally the Acetal resin showed the lowest values. [19, 25, 29, 30]

The final retentive forces after repeated cycles of insertion and removal showed lower values than retentive forces recorded after initial insertion of the thermoplastic prosthesis with gradual decrease of retentive forces for the two groups, however the decreased values of retentive forces are still within the acceptable range providing adequate retention. Moreover, the PEKK group in the present study showed significant difference only after cycles simulating three years of continuous use.

By the end of the repetitive cycles of insertion and removal simulating multiple years of polymeric RPDs use, a significant decrease of retention was recorded. Clasp fatigue, wear of the inner surface of the retentive tip in addition to mild abrasion of acrylic model abutments at the height of contour occlusal to the retentive undercut describes the decrease in retention. This is in agreement with the effect of the components friction retention proved in earlier studies. [19]

The resilient nature of Acetal resin clarifies the insignificant decrease in retentive force with the cycling insertion and removal as it show less deformation and higher flexibility. The retentive force values recorded with the limitation of the present study coincide with results of previous researches. [25, 31]

The insignificant difference in surface roughness between PEKK and Acetal groups may be credited to the similar hardness of both materials; the hardness of PEKK and Acetal Resin are 29 HV and 23 HV respectively. [32,33] Moreover, this insignificant difference in surface roughness may be attributed to the standardized finishing and polishing techniques performed in both groups using acrylic stone and sandpaper. On the other hand, over-polishing may interact with thermoplastic materials (PEKK and Acetal) resulting in a markedly rough surface which may cause increased bacterial adhesion. [34,35]

## CONCLUSION

Within the limitations of this study, it can be concluded that the PEKK may provide significantly better retention compared to acetal resin in Kennedy Class IV partial denture frameworks. However, both materials showed an insignificant difference regarding their surface roughness.

## REFERENCES


1. Benso, B., et al., Failures in the rehabilitation treatment with removable partial dentures. Acta Odontol Scand, 2013. 71(6): p. 1351-5.
2. Wiesli, M.G. and M. Özcan, High-Performance Polymers and Their Potential Application as Medical and Oral Implant Materials: A Review. Implant Dent, 2015. 24(4): p. 448-57.
3. Kumar S.N, et al. Comparison of Retention of Clasps Made of Different Materials Using Three-Dimensional Finite Element Analysis. Journal of Clinical and Diagnostic Research.2016;10(5): ZC13-ZC16.
4. Osada H, Shimpo H, Hayakawa T, Ohkubo Ch. Influence of thickness and undercut of thermoplastic resin clasps on retentive Force. Dent Mater J 2013.32: 381-389.
5. Peter TP. Creating Aesthetics with Thermoplastic clasps. The Dent Liner J. 2007; 11(3):6-13.
6. Najeeb S, Zafar MS, Khurshid Z, Siddiqui F. Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics. J Prosthodont Res. 2016;60(1):12-19.
7. Ewoldsen N. What are the clinical disadvantages and limitations associated with metal-free partial dentures? J Can Dent Assoc. 2007;73(1):45-6.
8. Abdulhadi L, Mourshed B. Clasp retention using variable undercuts depths. Dentika dent J 201015: 20-23.
9. Tannous F, Steiner M, R, Kern M. Retentive forces and fatigue resistance of thermoplastic resin clasps. Dent Mater 2012; 28:273–8.
10. Driscoll CF, Freilich MA, Guckes AD, et al. The Glossary of Prosthodontic Terms: Ninth Edition. J Prosthet Dent. 2017;117(5):e1-e105.
11. Zheng J, Aarts JM, Ma S, Waddell JN, Choi JJ. Different undercut depths influence on fatigue behavior and retentive force of removable partial denture clasp materials: a systematic review. Journal of Prosthodontics. 2023 Feb; 32(2):108-15.
12. El-Nogoomi M.I, Awaad N.M, and El-Sherbini N.N. Surface Roughness of 3D Printed Maxillary Denture Bases Versus Conventionally Fabricated Ones: In-Vitro Study. Advanced Dental Journal 2023;5(4):871 – 882.
13. Singh, S., J. N. Palaskar and S. Mittal. Comparative evaluation of surface porosities in conventional heat polymerized acrylic resin cured by water bath and microwave energy with microwavable acrylic resin cured by microwave energy. Contemp. Clin. Dent. 2013; 4: 147-151.
14. Al-Kheraif AA (2014): The effect of mechanical and chemical polishing techniques on the surface roughness of heat-polymerized and visible light-polymerized acrylic denture base resins. Saudi Dent J., 26: 56- 62.
15. Mohamed T, Baraka OA, Badawy MM. Comparison between Acetal Resin and Cobalt-Chromium Removable Partial Denture Clasp Retention: An in vitro Study. Int J Prosthodont Restor Dent. 2013 Apr 1;3(2):50-56.
16. Peng PW, Chen MS, Peng TY, Huang PC, Nikawa H, Lee WF. In vitro study of optimal removable partial denture clasp design made from novel high-performance polyetherketoneketone. J Prosthodont Res. 2024 Jan 12.
17. Harb IE, Abdel-Khalek EA, Hegazy SA. CAD/CAM constructed poly (etheretherketone)(PEEK) framework of Kennedy class I removable partial denture: A clinical report. J Prosthodont. 2019;28: e595–598.
18. Sadek S, Dehis W, Hassan H. Comparative Study Clarifying the Most Suitable Material to Be Used as Partial Denture Clasps. Open Access Maced J Med Sci. 2018; 6: 1111-1119.
19. Peng TY, Ogawa Y, Akebono H, Iwaguro S, Sugeta A, Shimoe S. Finite-element analysis and optimization of the mechanical properties of polyetheretherketone (PEEK) clasps for removable partial dentures. J Prosthodont Res. 2020; 64:250–256.
20. Zol SM, Alauddin MS, Said Z, Mohd Ghazali MI, Hao-Ern L, Mohd Farid DA, Zahari NAH, Al-Khadim AHA, Abdul Aziz AH. Description of Poly(aryl-ether-ketone) Materials (PAEKs), Polyetheretherketone (PEEK) and Polyetherketoneketone (PEKK) for Application as a Dental Material: A Materials Science Review. Polymers (Basel). 2023 May 2;15(9):2170.

21. Arda T, Arikan A. An in vitro comparison of retentive force and deformation of acetal resin and cobalt-chromium clasps. J Prosthet Dent. 2005; 94:267–74.

22. Yamazaki T, Murakami N, Suzuki S, Handa K, Yatabe M, Takahashi H, et al. Influence of block-out on retentive force of thermoplastic resin clasps: an in vitro experimental and finite element analysis. J Prosthodont Res. 2019; 63:303–8.

23. Abed, H., Al-Omari, A. Evaluation of Retention Force of Polyetheretherketone (PEEK) and Cast Cobalt-Chromium Circumferential Clasps: A comparative study. Al-Rafidain Dental Journal, 2022; 22(1): 19-27.

24. Tribst JPM, Dal Piva AMO, Borges ALS, Arȧjo RM, da Silva JMF, Bottino MA, et al. Effect of different materials and undercut on the removal force and stress distribution in circumferential clasps during direct retainer action in removable partial dentures. Dent Mater. 2020; 36: 179–86.

25. Mohammed, E., El Sayed, M. Effect of thermo-cycling on retentive forces of different esthetic thermoplastic clasp materials for removable partial denture. (In-vitro comparative study). Egyptian Dental Journal, 2022; 68(1): 647-658.

26. El- Segai, A., Abbas, M. Retention and Fatigue Resistance of Peek and Acetal Thermoplastic Resin Clasps. Egyptian Dental Journal, 2018; 64 (Issue 4 - October (Fixed Prosthodontics, Dental Materials, Conservative Dentistry & Endodontics): 4019-4025.

27. Marie A, Keeling A, Hyde TP, Nattress BR, Pavitt S, Murphy RJ, et al. Deformation and retentive force following invitro cyclic fatigue of cobalt-chrome and arylketone-polymer (AKP) clasps. Dent Mater. 2019;35:e113–21.

28. Gentz FI, Brooks DI, Liacouras PC, Petrich A, Hamlin CM, Ellert DO, et al. Retentive forces of removable partial denture clasp assemblies made from polyaryletherketone and cobalt-chromium: a comparative study. J Prosthodont. 2022;31:299–304.

29. Torii M, Nakata T, Takahashi K, Kawamura N, Shimpo H, Ohkubo C. Fitness and retentive force of cobalt-chromium alloy clasps fabricated with repeated laser sintering and milling. J Prosthodont Res. 2018; 62:342–346.

30. Lee WF, Chen MS, Peng TY, Huang PC, Nikawa H, Peng PW. Comparative analysis of the retention force and deformation of PEEK and PEKK removable partial denture clasps with different thicknesses and undercut depths. J Prosthet Dent. 2024 Feb;131(2):291.e1-291.e9.

31. Fathy SM, Emera RMK, Abdallah RM. Surface Microhardness, Flexural Strength, and Clasp Retention and Deformation of Acetal vs Poly-ether-ether Ketone after Combined Thermal Cycling and pH Aging. J Contemp Dent Pract. 2021 Feb 1;22(2):140-145.

32. Dhakshinya M, Maiti S, Nallaswamy D, Jessy P. Comparative analysis of surface characteristics and hardness of three-dimensional printed PEEK vs PEKK - as implant biomaterial. J Osseointegr 2024; 16(1): 16-22.

33. Salem SH, AlSourori AA, Mostafa MH. Effect of thermocycling on acetal resin versus PEEK surface hardness and flexure strength of implant-retained overdenture bars: in vitro study. Bulletin of the National Research Centre. 2023 Oct 19;47(1):152-157.

34. El-Din MS, Badr AM, Agamy EM, Mohamed GF. Comparison between Heat Cured Polymethylmethacrylate, Thermoplastic Polyamide and Thermoplastic Acetal in Regarding to their Surface Roughness: In Vitro Study. EC Dental Science 12.4 (2017): 156-167.

35. Batak B, Çakmak G, Johnston WM, Yilmaz B. Surface roughness of high-performance polymers used for fixed implant-supported prostheses. J Prosthet Dent. 2021 Aug;126(2): 254.e1-254.e6.