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Wear Resistance of CAD/CAM PEEK Versus Injection-Molded Acetal Resin Partial Denture Framework Materials: An In Vitro Comparative Study

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ABSTRACT

Aim: the purpose of this study was to assess the in vitro wear resistance of CAD/CAM milled polyether ether ketone (PEEK) and injection-molded acetal resin as partial denture framework materials.. **Subjects & methods:** PEEK and acetal resins were used to make 10 disc-shaped samples for each group with dimensions of 15 mm in diameter and 2 mm in thickness. Acetal resin samples were made using the injection molding method. However, PEEK samples were produced using computer-aided design and computer-aided manufacturing (CAD/CAM) technologies. After 10,000 cycles, wear resistance was evaluated after using a four-chamber chewing simulator (Robota) by measurement of weight loss. **Results:** The data analysis revealed a statistically significant difference in the weight loss mean values between the CAD/CAM PEEK samples and the Acetal Resin samples, with the PEEK sample showing more wear resistance .**Conclusion:** PEEK resin material displayed greater wear resistance than acetal resin material which suggests the potential benefits of utilizing PEEK in the construction of partial denture frameworks, especially in cases where wear resistance is a critical factor to consider.

KEYWORDS

Acetal resin, CAD/CAM, Partial Denture Framework, PEEK, Wear Resistance

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INTRODUCTION

Removable partial dentures (RPDs) have long employed cobalt chromium (Co/Cr) alloys as their frameworks, but these devices have several problems, including the aesthetic unattractiveness of the metal clasps and the development of hypersensitivity in individuals sensitive to Co/Cr [(1)]. In comparison to metal ones, polymer-based frameworks have some benefits, such as better aesthetics due to their transparency and color, higher cost-effectiveness, higher elasticity, ease of production, lightweight, low water sorption and solubility, and simplicity of duplication and repair [(2-4)].

To assure patient satisfaction with dental treatment and to protect the residual tissues, it has consequently seemed necessary to restore partially edentulous patients with RPD; manufactured by materials that meet the aesthetic requirements necessary to that end[5,6]. Thermoplastic high-performance polymer groups, such as polyether ether ketone (PEEK) and injection-molded polyoxymethylene (POM), commonly known as acetal resin, have been offered as an alternative to conventional polymethyl methacrylate (PMMA)[5,7].

Polyether ether ketone (PEEK) represents a biocompatible thermoplastic polymer with a high-temperature tolerance, characterized by an elastic modulus falling within the range of 3 to 4 GPa and a melting point proximate to 343˚C, in addition to exhibiting commendable mechanical properties[8-10]. Notably, PEEK has garnered attention as a substitute material for retentive caps in implant overdenture applications, offering advantages such as reduced wear, enhanced retention capabilities, heightened patient contentment, and the potential for decreased maintenance interventions [11, 12].

Polyoxymethylene (POM), also known as acetal resin, is synthesized through the polymerization of formaldehyde, offering an alternative to traditional polymethyl methacrylate (PMMA). The resulting homopolymer polyoxymethylene is formed by linking a sequence of alternating methyl groups with an oxygen molecule [13,14]. Acetal resin has been proposed as a substitute material for the framework of removable partial dentures, particularly for individuals with allergies to Co/Cr alloys, owing to its biocompatibility. It is purported to possess sufficient resilience and elastic modulus to be employed in the fabrication of retentive clasps, connectors, and support components for removable partial dentures [5].

An ideal framework polymer for removable partial dentures (RPD) should possess adequate mechanical properties to withstand reciprocating motion, impact, and excessive wear, as indicated in prior research [15]. Observations have revealed that the surfaces of the resin are prone to wear and abrasion during clinical use, particularly when exposed to hard objects. This susceptibility is attributed to the reduced wear resistance of the denture base resin, which creates an environment conducive to bacterial and fungal colonization. Such colonization has been linked to a spectrum of oral and general health conditions[16].

In the literature, there is little evidence regarding the difference in wear resistance between PEEK and acetal. Therefore, the purpose of this study was to assess the in vitro wear resistance of CAD/CAM milled PEEK and injected acetal partial denture framework materials. The null hypothesis of the study was that the difference in wear resistance between PEEK and acetal groups would be insignificant.

MATERIALS AND METHODS

Based on the research conducted by Alagwany et al.[16], the sample size calculation indicated that a statistical power of 80% and a minimum of 10 samples per group were sufficient to detect a significant difference between the groups with a 95% confidence interval. Subsequently, 10 disc-shaped samples of both PEEK and acetal resins, each measuring 15 mm in diameter and 2 mm in thickness, were prepared following the guidelines outlined in ISO standard 14569/2[17].

Samples preparation:

In this study, both PEEK samples and acetal resin samples were fabricated using different procedures. For the CAD/CAM PEEK samples; Figure (1), ten virtual disc-shaped 3D models with dimensions of 15 mm in diameter and 2 mm in thickness were designed using exocad DentalCAD 3.0 software (exocad GmbH, Darmstadt, Germany), and a solid volume was created from the surface elements. The design’s 3D virtual model was transferred using the STL file format [1,5]. According to the created design, the samples were then milled using CORiTEC® 150i PRO; a 5-axis milling machine (Imes-Icore GmbH, Hessen, Germany) [5].

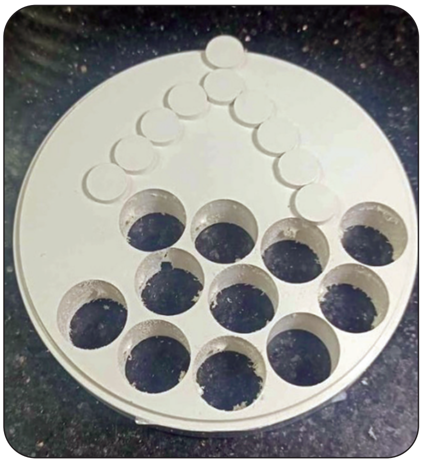

Fig. (1) CAD/CAM milled PEEK samples

For the injection-molded acetal resin samples; Figure (2), ten disc-shaped wax patterns with dimensions of 15 mm in diameter and 2 mm in thickness were made. These patterns were submerged in an investing plaster using a conventional flask and left to set for an hour. The flask containing the mold was then placed in boiling water for five minutes to remove the wax. The resultant mold was injected with thermoplastic acetal using the Thermopress 400 injection machine (Bredent GmbH & Co. KG, Senden, Germany). The acetal resin was then cured in a water bath at 74°C for 1.5 hours, following the manufacturer's guidelines [14, 16].

Fig. (2) Acetal resin processed samples

Finally, both milled PEEK samples and acetal resin samples underwent surface finishing, including polishing completed with 600, 800, and 1200 grit sandpaper, rinsing under running water, and then cleaning for two minutes in an ultrasonic cleaner [16, 18].

Wear testing procedures:

The specimens underwent a meticulous cleaning process prior to measurement, involving rinsing under running water and subsequent ultrasonic cleaning for two minutes to eliminate surface debris[14,19]. The wear testing was conducted using a four-station multimodal chewing simulator device (ROBOTA Industries, L.L.L., Egypt) for 2-body wear assessment; Figure (3). This testing apparatus is equipped with programmable logic-controlled equipment, enabling the simultaneous simulation of vertical and horizontal movements under thermodynamic conditions. Each station features a lower Teflon sample holder and an upper Jacob's chuck antagonist holder. During testing, all samples were subjected to consistent procedures, with an applied chewing force of approximately 7N or a weight of 700 grams. The wear assessment involved subjecting the samples to 10,000 cycles, equivalent to a revolution lasting approximately 54 minutes. Subsequent to the wear testing, the samples were removed from the holder, rinsed under running water, and cleaned in an ultrasonic cleaner for two minutes to eliminate any abrasive particles from the sample surfaces before measurement [16].

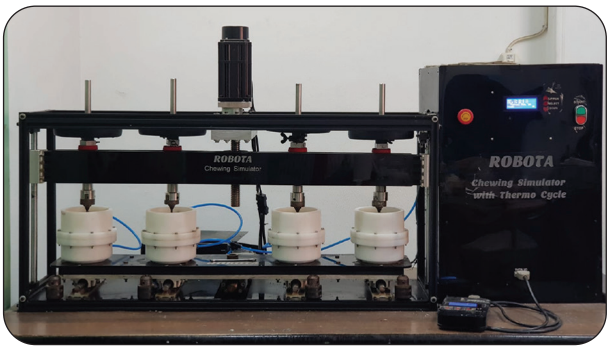

Fig. (3) ROBOTA chewing simulator

To determine the weight loss, the weight of each sample was measured at baseline and then after 10,000 chewing cycles to determine the weight loss. Samples were weighed with an accuracy of 0.0001 gram using the Cubis® II an electronic analytical balance (Sartorius Lab Instruments GmbH & Co. KG, Goettingen Germany), and the difference in weight before and after the chewing cycles (wear) was calculated from the equation; Wear = weight at baseline – weight after simulating chewing cycles[16].

Statistical analysis

The Kolmogorov-Smirnov test and the Shapiro-Wilk test were used to determine whether the distribution was normal. The acquired data were statistically analyzed using IBM® SPSS® software Version 20. An independent t-test was used to compare the means of the two groups. The results were deemed significant at P <0.05.

RESULTS

When using The Kolmogorov-Smirnov test and the Shapiro-Wilk test the significant level (P-value) was demonstrated to be negligible as P > 0.05, which suggested that the two sets of examined materials' data come from a normal distribution.

The results of the independent t-test revealed that the weight loss mean values for acetal samples were significantly higher than PEEK samples after 10,000 cycles of chewing simulation at t-value=3.79 and P-value=0.005. The PEEK samples recorded mean weight loss changes of (0.00084±0.00004 gram), however, the acetal samples recorded mean weight loss changes of (0.00095±0.00004) after 10,000 cycles of chewing simulation, as presented in table (1) and figure (3).

Table (1) *Comparison of the mean changes in weight loss values between the PEEK and Acetal samples:*

Variables		PEEK	Acetal	t-value	P-value
Weight loss	Min-Max	0.000798-0.000912	0.00089-0.00099	3.79	0.005*
	Mean± SD	0.00084±0.00004	0.00095±0.00004		

**; significant at P<0.05.*

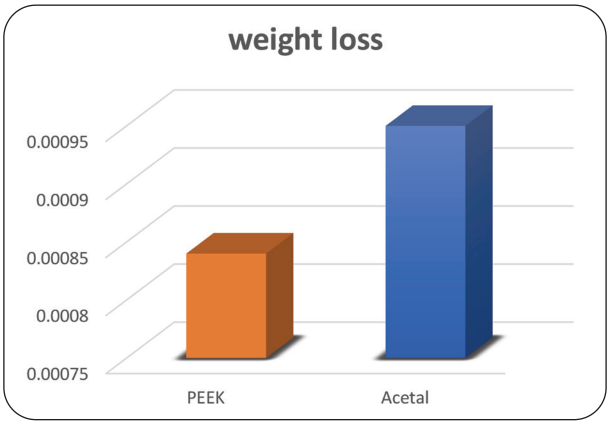

Fig. (4) A diagram illustrating the comparison of the mean weight loss values between the PEEK and Acetal samples.

DISCUSSION

With the development of novel polymers that have better biocompatibility, durability, and flexibility as well as aesthetic appeal and cost-effectiveness, polymer-based RPD prostheses tend to dramatically develop[20]. A perfect RPD framework polymer would also be impact-resistant, have suitable mechanical properties for reciprocating motion, and be resistant to excessive wear [15, 20]. Moreover, the relative benefits of any one RPD philosophy cannot be determined only based on clinical experience. [5] As a result, the current study's objective was to assess the in-vitro wear resistance of the milling PEEK and injected acetal resins as RPD materials because it is thought to be a crucial factor in determining whether a prosthesis will be successful or unsuccessful[14,16,21].

For the creation of RDP frames, POM, a material that may provide tooth-colored aesthetics, is appropriate[22,23]. It is also thought to have a high enough elastic modulus and durability to be utilized in the development of retentive clasps, connectors, and support elements for removable partial dentures[5,23]. Additionally, especially in the copolymer variety, Acetal polymer is renowned for its resistance to wear and water sorption. Additionally, it is thought to be a good framework and clasp material for RPD in patients with Co-Cr framework allergies[5,13]. As a result, the current study's test framework RPD material was chosen to be acetal resin.

PEEK is also acknowledged as a good material for the framework of a removable denture and all of its pieces, including the aesthetic appeal of the clasp, due to its high mechanical and exceptional biocompatibility features[13]. Additionally, compared to a normal metal framework display, the white color of the PEEK framework offers a more diversified visual process [5]. As a result, PEEK resin was chosen for the current study's test framework RPD material.

In the current study, the classic lost wax process using a vacuum press apparatus and CAD/CAM technologies were used to create acetal and PEEK prosthetic materials for RPD frameworks respectively [5]. This might make it possible to design RPDs that are stable, and comfortable, but less intrusive. Since several of these polymers are heat-resistant, it is possible to sterilize the prosthesis using an autoclave [20].

The findings of this study revealed that there was a significant difference between the mean weight loss changes of PEEK samples and acetal samples therefore, the null hypothesis of this study was rejected. The results of this current investigation regarding wear revealed that the acetal resin had significantly lower wear resistance than PEEK. This could be explained by Acetal frameworks being more resilient than PEEK which further reflected the difference in elastic modulus between the two materials (PEEK had a higher elastic modulus than acetal).

The assertion that acetal frameworks are more resilient than PEEK introduces an important consideration. Resilience, in the context of materials science, denotes the ability of a material to absorb energy and deform elastically under stress, subsequently returning to its original shape. This characteristic is pivotal in assessing a material's capacity to withstand wear and abrasion over time. The higher resilience of acetal resin may contribute to its lower wear resistance, as it could potentially undergo greater deformation when subjected to abrasive forces, leading to accelerated wear [7, 23].

These results support earlier research by Fathy et al.[13], which found that PEEK polymers had superior surface and mechanical qualities than acetal polymers. However, the results of the current investigation disagreed with the results of Alagwany et al. [16] who found that the acetal resin can be used as an alternate material to the traditional heat-cured acrylic resin denture base material because there was no statistically significant difference between the two groups regarding wear resistance.

The observed differences in wear resistance between Acetal resin and PEEK can be attributed to various factors related to the polymer chemistry and microstructure of the materials. The degree of crosslinking within the examined resins plays a crucial role in determining their mechanical properties, including wear resistance. Acetal resin, known for its heavily cross-linked polymer structure, may exhibit lower wear resistance compared to PEEK due to the specific arrangement of its molecular chains.

Additionally, the presence of inorganic phases within the resins can influence their mechanical performance, potentially contributing to the disparity in wear resistance. Understanding the polymer chemistry and microstructural characteristics of these materials is essential for elucidating the underlying mechanisms governing their wear behavior, thereby providing valuable insights for material selection in various applications [13, 18].

Moreover, PEEK contains 20% ceramic material with a grain size of 0.3-0.5 m. The small size of the ceramic fillers enables them to occupy the spaces between the chains of the PEEK polymer, thereby reducing chain mobility and impeding the penetration of various anti-aging treatments[5,7,24]. The initial composition of PEEK may have been designed to prioritize its exceptional strength properties in comparison to Acetal resin.

Furthermore, PEEK's stiffness surpasses that of Acetal resin, which lacks the ceramic filler inorganic phase. This disparity in stiffness can be further enhanced by the presence of inorganic filler, in addition to its semi-crystalline nature (30-35% crystalline). These factors potentially account for the superior wear resistance observed in PEEK samples compared to the less rigid Acetal resin in this current investigation [13, 18].

The superior wear resistance of PEEK resin observed in the study implies its potential to contribute to the longevity and functional performance of partial denture frameworks. By withstanding simulated chewing conditions more effectively than acetal resin, PEEK may offer enhanced durability, reducing the likelihood of wear-related issues and the need for premature replacements. This could translate to improved clinical outcomes for patients, including greater comfort, stability, and overall satisfaction with their dental prostheses.

The study's limitations arise from its sole reliance on in vitro testing to assess the wear resistance of PEEK and acetal resin, which may not fully represent their performance in real clinical settings. In vitro testing does not always accurately reflect wear behavior in vivo, necessitating further research to investigate the long-term clinical performance of PEEK versus acetal resin partial denture. Additionally, the study overlooked the impact of different surface treatments on the wear resistance of PEEK RPD, despite the significant influence of surface treatments on wear resistance. This omission calls for additional investigation to comprehend how diverse surface treatments may lead to distinct wear properties. Moreover, the controlled conditions of in vitro testing do not replicate the intricate oral cavity environment, disregarding the potential effects of saliva, bacteria, and other factors that intricately influence the wear resistance of dental materials.

CONCLUSIONS

From the study's findings, it can be concluded that CAD/CAM PEEK material exhibited superior wear resistance compared to acetal resin when exposed to simulated chewing conditions, highlighting its potential advantages in partial denture framework construction, particularly in situations where wear resistance is a key consideration.

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مقاومة التآكل بين مواد أطر أطقم الأسنان الجزئية المُصنعة من مادة البولي-ايثر- ايثر-كيتون بواسطة تقنية الكاد/كام مقابل مادة الأسيتال المصنعة بتقنية الحقن المصبوب : دراسة مقارنة في المختبر

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الملخص :

الهدف: الغرض من هذه الدراسة هو تقييم مقاومة التآكل في المختبر بين طقم الأسنان الجزئي من مادة البولي-ايثر- ايثر-كيتون بواسطة تقنية الكاد/كام مقابل الطقم الجزئي المصنوع من مادة الأسيتال بتقنية الحقن المصبوب.

المواد والأساليب: مادة البولي-ايثر- ايثر-كيتون ومادة الأسيتال استخدمو لعمل 10 عينات علي شكل قرص لكل مجموعة بأبعاد 15ملم للقطر و2ملم للسُمك.عينات الأسيتال صممت بواسطة الحقن المصبوب. عينات مادة البولي-ايثر- ايثر-كيتون صممت وصنعت بمساعدة الكمبيوتر بتكنولوجيا الكاد/كام. بعد 10000 دورة, مقاومة التآكل قيمت بعد استخدام محاكي مضغ من أربع غرف (روبوتا) عن طريق قياس فقدان الوزن.

النتائج: كشف تحليل البيانات عن وجود فرق ذو دلالة إحصائية في قيم متوسط فقدان الوزن بين عينات البولي-ايثر-ايثر-كيتون ومادة الأسيتال وعينات الأسيتال, مع عينات البولي-ايثر-ايثر-كيتون تظهر المزيد من مقاومة التآكل.

الخلاصة: اظهرت مادة البولي-ايثر-ايثر-كيتون مقاومة تآكل أكبر من مادة الأسيتال مما يشير إلى الفوائد المحتملة لاستخدام مادة البولي-ايثر-ايثر-كيتون في بناء أطر أطقم الأسنان الجزئية . خاصة في الحالات التي تكون فيها مقاومة التآكل عاملا حاسما يجب مراعاته..

الكلمات المفتاحية: الأسيتال. الكاد/كام, إطار طقم الأسنان الجزئي , البولي-ايثر- ايثر-كيتون, مقاومة التآكل.