International Journal of Chemical and Biochemical Sciences
(ISSN 2226-9614)
Journal Home page: www.iscientific.org/Journal.html

"CAD/CAM peek or injection-molded acetal resin: which has higher color stability in removable partial denture frameworks?"

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Abstract

The study aimed to evaluate the color stability of CAD/CAM milled polyether ether ketone (PEEK) and injection-molded acetal resin removable partial denture (RPD) framework materials in vitro. Sixty samples, measuring 15 mm in diameter and 2 mm in thickness, were produced from PEEK and acetal resins, with 30 samples in each group. The acetal resin samples were created using the injection molding technique, while the PEEK samples were manufactured using computer-aided design and computer-aided manufacturing (CAD/CAM) technology. Subsequently, the samples in each group were equally divided into three subgroups (n= 10) based on the immersion solution: artificial saliva subgroup, ginger subgroup, and coffee subgroup. The color change was assessed using a reflective spectrophotometer after immersion in the previous staining solutions, with all samples kept in an incubator at 37 °C for 4 weeks. Color change results revealed that both PEEK and acetal samples were more negatively affected when immersed in the coffee solution (acidic pH) compared to the ginger solution (alkaline pH), with the least negative effect observed in the normal pH (artificial saliva). Additionally, the color change values in the acetal samples were significantly higher than those in the PEEK samples across all tested solutions (artificial saliva, ginger, and coffee). The PEEK material demonstrated enhanced color stability in comparison to acetal resin, suggesting its potential suitability for dental applications that require superior color stability, particularly in situations with high aesthetic demands.

Keywords: Acetal resin, CAD/CAM, Color stability, PEEK, Partial denture framework.

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1. Introduction

Cobalt chromium (Co/Cr) alloys have been used as RPD frameworks for a long time. Still, these materials have significant drawbacks, including the aesthetic unattractiveness of the metal clasps and the production of hypersensitivity in patients sensitive to Co/Cr [1]. Polymer-based frameworks have some advantages over metal, including improved aesthetics due to their translucency and color, greater cost-effectiveness, higher elasticity, ease of production, lightweight, low water sorption and solubility, and ease of repair and replication [2-4]. It has therefore seemed crucial to restore partially edentulous patients with RPDs made of materials that satisfy the aesthetic requirements necessary to ensure patient satisfaction and designed on biomechanical principles to preserve the remaining tissues [5, 6]. As an alternative to traditional polymethyl methacrylate (PMMA), thermoplastic high-performance polymer groups such as PEEK and injection-molded polyoxymethylene (POM), also known as acetal resin, have been introduced [5, 7]. PEEK is a high-performance thermoplastic polymer that is biocompatible, with an elastic modulus of between 3 and 4 GPa, a melting point of around 343°C, and sufficient mechanical characteristics [8, 9]. PEEK has attracted attention due to its favorable physical, mechanical, and chemical properties, making it suitable for applications in a wide range of dental prostheses, including fixed and removable restorations, implant abutments, and occlusal splints [10]. In prosthetic dentistry, PEEK has been utilized as an alternative partial denture framework material to traditional (Co/Cr) alloys, offering lower wear attributes, increased retention, enhanced patient satisfaction, and a potential reduction in required maintenance events. [5, 7]. As an alternative to traditional PMMA, formaldehyde is polymerized to create POM or acetal resin. An oxygen molecule connects a sequence of alternating methyl groups to form the homopolymer polyoxymethylene [11, 12]. Due to its biocompatibility, acetal resin has been suggested as a replacement material for the framework of removable partial dentures for individuals who have allergies to Co/Cr alloys. It is said to have a high enough resilience and elasticity modulus to be used in the creation of removable partial dentures' retentive clasps, connections, and support components [5]. Color stability is indeed a crucial factor in the success of a dental prosthesis. The ability of an RPD material to maintain its color over time can significantly impact patient satisfaction and the overall effectiveness of the prosthesis [12, 13]. However, these materials have been reported to exhibit several drawbacks, including issues related to water absorption, susceptibility to bacterial contamination, aging-related discoloration, warping, color deterioration, challenges in polishing, limitations in relining, and a manufacturing process sensitive to technique [14, 15]. Moreover, these materials have a weak connection to the repairing resins [16]. Therefore, the purpose of this study was to assess the color stability of injected acetal resin and milled polyether ether ketone (PEEK) removable partial denture framework materials in vitro. The null hypothesis of the study was that the color changes among PEEK and acetal samples would be insignificant.

2. Materials and Methods

According to Polychronakis et al. [17], power sample size calculation using the G-POWER software (G*Power version 3.0.10; Germany) indicated that 10 samples per subgroup were necessary to detect a significant difference in color stability between the PEEK and acetal groups, with a 95% confidence interval and a power of 80%. Sixty samples, comprising 30 for PEEK and 30 for acetal, were utilized to assess color stability, with 10 specimens dedicated to each staining solution (artificial saliva, ginger, and coffee).

2.1. Samples preparation

A total of 60 samples, each measuring 15 mm in diameter and 2 mm in thickness, were fabricated from PEEK and acetal resins according to ISO standard number 14569/2 [18], with 30 samples in each group. PEEK samples; shown in Figure 1, were manufactured utilizing computer-aided design and computer-aided manufacturing (CAD/CAM) technology, while acetal resin samples; shown in Figure 2, were produced using the injection molding technique. The process for PEEK samples involved designing a virtual 3D model with the required dimensions using exocad DentalCAD 3.0 software (exocad GmbH, Darmstadt, Germany). Subsequently, the surface elements were converted into a solid volume, and the 3D virtual model was then transferred in STL file format. The PEEK polymer discs (BioHPP; Bredent GmbH, Senden, Germany) were subsequently subjected to 3D milling using the CORiTEC® 150i PRO, a 5-axis milling machine (Imes-Icore GmbH, Hessen, Germany), to achieve the planned design[1, 5]. For the acetal resin samples, wax patterns, shown in Figure 2 measuring 15 mm in diameter and 2 mm in thickness were initially created. These wax patterns were then immersed in plaster using an investing plaster in a traditional flask and allowed to harden for one hour. Subsequently, the flask containing the mold was placed in boiling water for five minutes to soften and remove the wax. The thermoplastic acetal granules, Bio Dentaplast (Bredent GmbH & Co. KG, Senden, Germany), were injected utilizing the Thermopress 400 injection machine (Bredent GmbH & Co. KG, Senden, Germany), and subsequently cured in a hot water bath following the manufacturer's guidelines [12, 19]. All samples were finished using 600, 800, and 1200-grit silicon carbide paper and then further polished with Universal Polishing Paste (Ivoclar Vivadent, Schaan, Liechtenstein). Subsequently, they were rinsed under running water and subjected to a 10-minute cleaning cycle in an ultrasonic cleaner [17].

2.2. Preparation of staining solutions

The artificial saliva solution was prepared by mixing the following ingredients: 1g sodium carboxymethylcellulose, 4.3g xylitol, 0.1g potassium chloride, 5mg calcium chloride, 40mg potassium phosphate, 1 mg potassium thiocyanate and 100g deionized water. The staining solution for ginger was prepared by adding 20 g of ginger (Royal Herbs S.A.E, Ottoman Group, Shabramant, Giza, Egypt) to 1000 ml of boiled water for 5 minutes. The solution was stirred every 5 minutes for 10 seconds until it cooled to room temperature and then filtered through a filter paper. Similarly, the coffee solution was prepared by adding 20 g of coffee (Nescafe Classic, Nestle Egypt) to 1000 ml of boiled water for 5 minutes. The solution was stirred every 5 minutes for 10 seconds until it cooled to room temperature and then filtered through a filter paper [13, 20]. Subsequently, samples were immersed in sealed glass containers, each containing 100 ml of the prepared solution and the containers were kept in a laboratory incubator (CBM. Torre Picenardi (CR), Model 431/V, Italy) at 37ºC for 4 weeks. The immersion solutions were renewed every 12 hours.

2.3. Color change testing procedures

Before measurement, the samples underwent cleaning under running water and then in an ultrasonic cleaner for ten minutes to eliminate any surface debris [12, 21]. The color of each sample was assessed at the baseline time (T0) and after 4 weeks (T1) following immersion using computational technique software [13, 20] employing a spectrophotometer with a digital camera (Model RM200QC, X-Rite, Neu-Isenburg, Germany), and image processing software. The aperture size was standardized to 4 mm, and the specimens were positioned at the center of the measuring port. To mitigate potential errors stemming from measurements at different regions, each sample underwent three measurements at randomly selected spots [21]. The Commission Internationale de l'Eclairage (CIE) Lab system was employed to compute differences between the baseline and post-immersion colors, and color difference (ΔE) values were determined according to the following equation [21]:

$$\Delta E^*=[(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}$$

Where, L*: indicates White-Black, $\Delta L=L_t-L_0$, a*: indicates Redness-Greenness, $\Delta a = a_t - a_0$, b*: indicates Yellowness-Blueness, $\Delta b = b_t - b_0$ (L_t, a_t, b_t: values after immersion/ L_0, a_0, b_0: values at baseline).

2.4. Statistical analysis

The normality of the distribution was assessed using the Shapiro-Wilk and Kolmogorov-Smirnov tests. The statistical analysis of the collected data was performed using SPSS® Statistics Version 20 software. ANOVA test was employed to compare numerical data among groups with a normal distribution, while an independent t-test was utilized to compare means between two groups. Findings were considered significant at a significance level of $p < 0.05$.

3. Results

After the normality of the given data was tested using the Shapiro-Wilk test and the Kolmogorov-Smirnov test, the results indicated that the significant level (P-value) was insignificant, as P-value > 0.05. This suggests that the data originates from a normal distribution (parametric data) in the two tested groups regarding the material type and immersion solutions (artificial saliva, ginger, and coffee). The finding of the independent t-test indicated that the color change values observed in the acetal samples were significantly higher than those in the PEEK samples across all tested solutions (artificial saliva, ginger, and coffee), as detailed in Table 1. Furthermore, the results of the one-way ANOVA test demonstrated a statistically significant difference in color change between the solution averages for both PEEK and acetal materials, as presented in Table 1. Additionally, the intergroup comparison revealed that the color change values for PEEK and acetal samples exhibited an increasing trend corresponding to the change in the type of solution, with the order being saliva < ginger < coffee, as outlined in Figure 4.

4. Discussion

The null hypothesis of this study was that the color stability of PEEK and acetal resin materials would not be significantly affected by differences in the pH of the immersion solution. However, the study's findings disproved this null hypothesis. The polymer-based RPD prostheses tend to significantly develop with the introduction of new polymers that have improved biocompatibility, durability, and flexibility as well as aesthetic appeal and cost-effectiveness. Additionally, framework polymer should offer long-term color stability, cosmetically complement the mouth's mucosal tissues, and should be chemically stable [22]. Therefore, the goal of the current study was to compare the color stability of the milled PEEK and injected acetal resins as RPD materials because it is regarded as a key determinant of the success or failure of a prosthesis [12, 13]. The material POM, which can provide tooth-colored aesthetics, is appropriate for making RDP frameworks [23, 24]. Moreover, it is believed to have a high enough resilience and elastic modulus to be used in the creation of retentive clasps, connectors, and support components for removable partial dentures [5, 24]. Therefore, acetal resin was selected as a test framework RPD material in this current study. Moreover, because high mechanical and great biocompatibility qualities define PEEK, it is recognized as a good material for the framework of a removable denture and all of its parts, including the clasp's aesthetic appeal [11]. Additionally, the PEEK framework's white color offers a more varied aesthetic process than the typical metal framework display does [5]. Therefore, PEEK resin was selected as a test framework RPD material in this current study. In this current investigation, PEEK and acetal prosthetic materials for RPD frameworks are made either utilizing CAD/CAM technologies or the traditional lost wax method with a vacuum press apparatus [5]. This may enable the creation of RPDs that are stable and comfortable yet less obtrusive. Many of these polymers can also withstand heat, allowing for the autoclave sterilization of the prosthetics [22]. When evaluating color changes, visual examination can be considered a distinct physiological process. In contrast, the utilization of a spectrophotometer device for assessing color alteration eliminates subjective interpretations and facilitates the detection of subtle color changes that may not be perceptible to the naked eye. [13, 17]. Spectrophotometers were chosen for the current experiment because they are known to record the amount of light reflected by an object, although they have the drawback of scattering, particularly on convex surfaces [12, 17]. Moreover, in this investigation a color system known as CIE was employed; L*a*b is a constant color scale that encompasses all the colors visible to the human eye; as a result, it is appropriate for investigating color variations in various dental materials available on the market [13, 21]. The color stability of CAD/CAM milled PEEK and acetal resin specimens was assessed following a four-week storage period in different storage media, which were chosen to mimic the pH ranges of beverages commonly consumed by individuals. Specifically, coffee was utilized to represent an acidic medium, ginger was employed to simulate an alkaline medium, and artificial saliva with a physiologic pH was included as the control group for comparison. [13, 20]. According to the results of this investigation's color change tests, both types of tested resins change color when exposed to saliva, ginger, and coffee. This may be attributed to the susceptibility of the materials utilized in this experiment to water sorption, potentially resulting in hydrolysis and subsequent change of the original material color. [13, 17]. This water sorption is a crucial indicator because if the resinous material can absorb water, it can absorb other liquids as well [13, 25]. This agreed with the findings by Porojan et al., [26] showed that within the first week of immersion, both the reinforced and unfilled PEEK materials examined reached water saturation with no discernible differences.

The present investigation's findings indicate that PEEK exhibits superior color stability compared to acetal resin, aligning with prior research by Fathy et al. [11], which highlighted the enhanced surface and mechanical properties of PEEK polymers relative to acetal polymers. These results are consistent with the earlier study conducted by Polychronakis et al. [17], which demonstrated the gradual discoloration of both materials following prolonged exposure to staining agents, with acetal resin exhibiting more pronounced discoloration than PEEK resin. These results could be explained by variations in the polymer chemistry of the investigated resins, the degree of crosslinking, the existence of another inorganic phase, and the resistance to fluid sorption. The microstructure of the PEEK employed in this study is predicated on it being a strongly crosslinked polymer [11, 17]. Moreover, PEEK has extremely stable chemical and physical characteristics since it possesses an aryl ring that contains ketone and other groups [26].

Figure (1): CAD/CAM milled PEEK samples

Figure (2): Acetal resin processed samples

Figure 3: Reflective spectrophotometer device

Table 1: Comparison of the color change for PEEK and acetal regarding the material type.

Variables	PEEK	Acetal	t-value	P-value
Artificial saliva	0.0539 ± 0.007^{C}	0.0821 ± 0.010^{C}	5.05	<0.001*
Ginger	0.108 ± 0.004^{B}	0.125 ± 0.014^{B}	2.58	0.032*
Coffee	0.157 ± 0.005^{A}	0.181 ± 0.003^{A}	7.54	<0.001*
P-value	<0.0001*	<0.0001*		

Different uppercase letters in the same column are statistically significant.
*; significant at P<0.05.

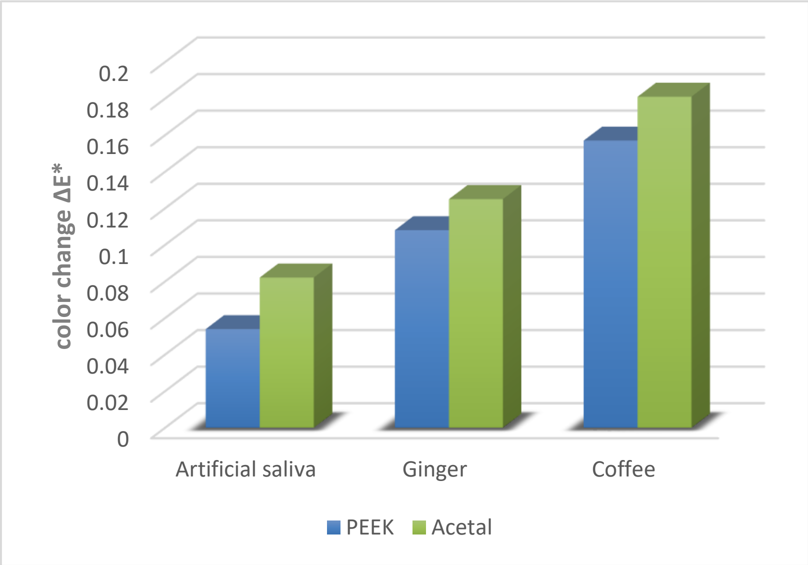

Figure 4: A diagram illustrating the comparison of the mean color change values between PEEK and Acetal.

Additionally, PEEK has 20% ceramic filler with 0.3-0.5 µm grain size. Ceramic fillers' small size makes it possible for them to enter and fill the area between the PEEK polymer's chains, which limits chain mobility and lessens the penetration of various aging treatments [5, 7, 26]. Also, Polychronakis et al., [17] stated that the increased discoloration of acetal was likely caused by its rougher surface than PEEK's after polishing. The authors claimed that acetal discolors more than PEEK since it absorbs and diffuses water more so than PEEK, which has 20% ceramic fillers. In agreement with the results of this current investigation, the findings of Gómez-Polo et al., [12] showed that maintaining acceptable aesthetics is impossible when the temporary acetal resins' color shift reaches the clinically acceptable level. This could explain the inferior color stability of Acetal resin in comparison with PEEK in this current investigation. The findings of the current study were inconsistent with those of a previous study by Kamal et al.[27], which examined the color stability of three CAD CAM milled denture base materials: PEEK, Acetal Resin, and Acrylic Resin. The previous study reported that the acetal resin denture base material exhibited the highest color stability. This discrepancy may be attributed to variations in immersion times, as the previous study[27] assessed color changes after 7 days of immersion, whereas the current study conducted immersion for 4 weeks. Additionally, the acetal resin samples in the present study were produced using the injection molding technique, whereas in the previous study, acetal resin samples were manufactured using CAD/CAM technology [27]. The study limitation was that evaluation was solely conducted in vitro, disregarding potential variations in color stability that may arise in clinical situations due to factors such as patient-specific oral conditions, oral hygiene practices, and exposure to a wide range of dietary and environmental factors. Additionally, while the study considered the pH of the immersion solutions, it did not comprehensively address other environmental factors present in the oral cavity, such as temperature variations, exposure to light, and the presence of oral microflora, which could influence the color stability of the materials.

5. Conclusions

The PEEK material exhibited enhanced color stability when compared to acetal resin, indicating its potential suitability for dental applications that demand superior color stability, especially in scenarios with high aesthetic requirements. Moreover, it was observed that the acidic nature of the coloring solution could have a detrimental effect on the color stability of the resin.

Conflict of Interest

There are no conflicts of interest among authors.

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