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RESEARCH

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Effect of thermocycling on acetal resin versus PEEK surface hardness and flexure strength of implant-retained overdenture bars: in vitro study

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Abstract

Background Implant-supported mandibular overdentures with bar attachments are considered an excellent option for a completely edentulous mandible. It provides a long-lasting and reliable solution to restore function and aesthetics to the patient. Many materials can be used for the construction of bar attachments, among which are PEEK and Acetal resin materials. The choice between PEEK and Acetal bar attachments eventually depends on the application, considering factors such as load-bearing requirements, biocompatibility, adaptability, and ease of use.

Methods Twelve 3D-printed edentulous mandible models each received two implants. Models were then divided into two equal groups. Group1: Six models with PEEK bars were fabricated by thermo-pressed technique while Group 2: Six models with Acetal resin bars were fabricated by thermo-pressed technique. Surface hardness and flexure strength were then evaluated and statistically analyzed before and after thermocycling.

Results PEEK group revealed significant higher surface hardness than Acetal resin before and after thermocycling. Regarding flexure strength, PEEK showed an insignificant increase than Acetal before thermocycling; however, the PEEK group displayed much higher values than the Acetal group following the thermocycling, resulting in a significant difference between the two groups.

Conclusions Bar made of PEEK showed more promising surface hardness and flexure strength than Acetal resin bar.

Keywords Implant overdenture, PEEK bar, Acetal bar, Surface hardness, Flexure strength

Background

The ability of implant-supported overdentures to improve dental health and overall quality of life in those who are completely edentulous is what has contributed to their popularity. Studies have demonstrated that implant overdentures can offer superior retention and stability compared to traditional complete dentures, enhancing patient satisfaction and quality of life in terms of dental health. For a totally edentulous mandibular arch, a two-implant overdenture is a popular implant overdenture treatment option because it enables appropriate support and denture retention (Bajunaid et al. 2022).

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Implants splinted together with bars could reduce the risk of overload for each implant due to the enlarged surface area, load sharing between implants, and improved biomechanical distribution (Akca 2007). The ability of the bar to reduce the possibility of micromotion at the bone-implant interface may aid in the effective osseointegration of immediately loaded implanted dentures (Al-Harbi 2018). According to their biomechanical behavior, bar attachments are divided into rigid and resilient attachment.

Bar implant-supported overdentures can be made from a variety of materials. These materials include polyetheretherketone (PEEK), cobalt-chrome (Co-Cr), zirconia, titanium and Acetal. According to studies, stress values in implant-supported overdentures are not significantly impacted by the material utilized to fabricate the bars. The material selected, however, may change based on the patient's oral health, anticipated occlusal forces, and aesthetic needs. The use of digital technology in the creation of implant-supported reconstructions, which might include utilizing new materials or manufacturing procedures than conventional techniques, has also been studied recently (Kümbüloğlu et al. 2022).

PEEK has a number of benefits when used in implant-supported prostheses, including increased lightness, enhanced appearance, biocompatibility, and an elastic modulus that is comparable to bone. PEEK is a good option for dental applications because research has proven that it has great mechanical characteristics. PEEK is also more versatile and practical for dental prosthesis owing to its flexibility to be integrated into other materials. The use of PEEK for fixed and removable prostheses, implants, and obturators is also being researched, as is its potential for bone regeneration. Overall, the application of PEEK has intriguing chances to enhance the functionality and durability of dental prosthesis supported by implants (Blanch-Martínez et al. 2021).

On the other hand, another thermoplastic material which is widely used in removable prosthodontics is Acetal resin. It has superior aesthetics, high resistance to abrasion, excellent tensile and shock strength. Acetal resins are incredibly adaptable engineering materials. There is bridge building polymer between conventional plastic and metal. They make the perfect material for the creation of dental prosthesis because they provide the durability of metal and the comfort and flexibility of plastic.

However, there has not been much research done on how this material affects the functional strains on the tissues that support the implant when it serves as the base material for an implant. These qualities make Acetal resin an excellent replacement for acrylic resins and metals in many prosthetic applications, in addition to its exceptional cosmetic performance. Due to these qualities, it is a perfect material for partial denture frames, single-pressed unilateral partial dentures, pre-formed clasps, occlusal splints, and implant abutments. To further improve its potential for usage as a base material for dentures, it was strengthened with glass fiber and glass spheres (Alqutaibi et al. 2023; Yerliyurt et al. 2023; Ozkan et al. 2005).

Acetal is also characterized by having a strong elastic memory, a low thermal conductivity, stiffness, and resistance to organic solvent. It also has the advantage of being non-toxic and non-allergenic. After 300 h of thermocycling, clinically acceptable hue changes have occurred (Prashanti 2012).

A necessary mechanical characteristic that identifies a material's resistance to scratching and irreversible deformation is its hardness. The majority of studies have looked at how mechanical fatigue cycling affects the mechanical characteristics of Acetal resin and other thermoplastic materials. Another well-known high-performance aromatic thermoplastic polymer is polyetheretherketone (PEEK). Depending on the manufacturing process, it is a two-phase, semi-crystalline polymer with a crystallinity of between 30 and 35% and is distinguished by strong mechanical capabilities and great biocompatibility (Tannous et al. 2012; Schwitalla et al. 2015). There are insufficient data on the minimal thickness that could still offer sufficient mechanical strength to survive the masticatory stresses without failing, as well as sufficient data to assess the effect of a change in thickness on flexural strength.

The morphology and mechanical properties of the materials may change as they age, which could have an impact on how well they operate in clinical settings. Insufficient research has been done on how PEEK and Acetal break down in the oral cavity. The effect of thermal cycling on a material's surface characteristics is not well covered in the literature at this time (Taşın and Ismatullaev 2022). Hence, our study aimed to evaluate the effect of thermocycling aging on the hardness and flexure strength of PEEK and Acetal resin bar attachment. The null hypothesis to be verified was that there is no difference between PEEK and Acetal resin in terms of how thermocycling aging affects hardness and flexure strength.

Methods

Laboratory procedures

There are twelve 3D-printed edentulous mandible models (Selmodels, Ref. DM 602, C/Besalú, 76, local (08026 Barcelona), Spain). Two dental implants were placed into the models that were 3.8 mm in diameter and 12 mm long. Then, Ti-base abutments were attached to each implant (Fig. 1); then spray powder (Alldent, Germany) was

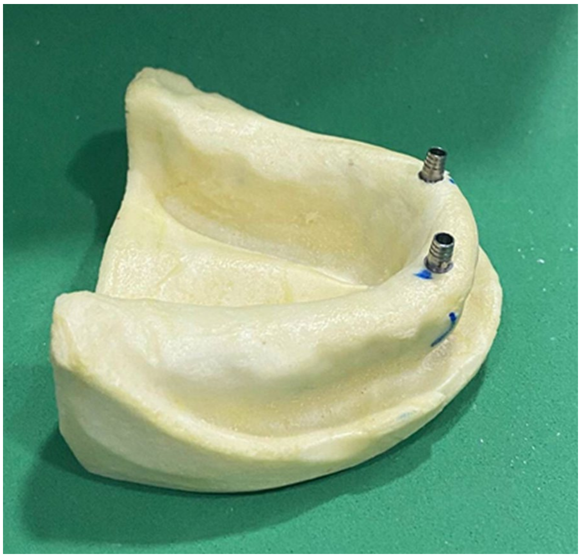

Fig. 1 Ti-base abutments

applied to the model with the bar fastened on, and it was scanned using a desktop scanner (Medit T500) to obtain the STL file for the model and bar. The Meshmixer software (MESHMIXER) was used to import the STL file of the bar and model (Programme Version 3.5, Autodesk). Exocad is used for the fabrication of bar attachments connecting two Ti-base attachments. Exocad software was used to design a bar following the mandibular model curvature (Fig. 2). CAM technology was used when a wax bar was fabricated from wax blocks using a milling machine. Wax bars were invested and then burned out, leaving a mold of CAD/CAM-fabricated bars.

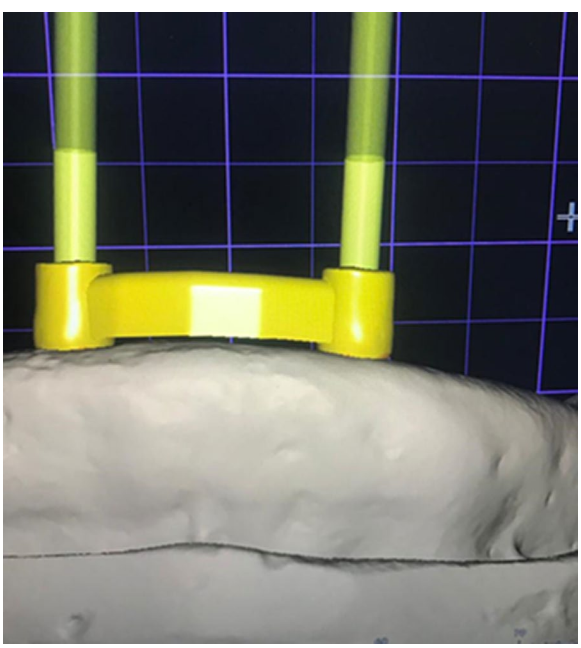

Fig. 2 Exocade bar design

Then, the models were divided into two groups, each with six models. Group 1: PEEK was thermo-pressed in the mold and then attached to the implant. Group 2: Acetal was thermo-pressed in the mold and then attached to the implant.

The required bar was made using a 3D printer using commercial exocad software, and the PEEK sample was then prepared in accordance with the manufacturer's instructions. The sprue and casting ring were prepared. The mold is heated in a customized PEEK heating furnace after the addition of the unique investment material since the ideal preheating temperature is between 850°C and 900°C. Heat the mold, and then add PEEK (BioHPP) granules before transferring it to the customized For2Press PEEK pressing machine. Finally, each bar was finished and condition according to the manufacturer's guidelines after the investment material was removed.

Regarding the Acetal resin bar, spruing was carried out in accordance with the manufacturer's instructions after the necessary bar was created using CAD/CAM and 3D printing technology. A specific dental flask was employed to house the pressing machine (Thermopress 400). Wax removal was performed before the resin was plasticized at 220°C for 15 min using a special metallic cartridge filled with the thermoplastic Acetal grains. A class III stone with individually controllable expansion was then used for the investing process. After pressing, the investment material was removed, and each bar was then finished and condition according to the manufacturer's requirements (Fig. 3).

Fig. 3 Acetal resin bar

Thermocycling testing

Prior to thermocycling, the baseline hardness and flexure strength were determined. All overdentures with attachments experienced manual thermoscycling using SU Poly-tubs, one kept at 5 1° and the other at 55 1°. 5000 heat cycles total—equivalent to sixth months of use in the oral cavity—were applied to the test samples. Each cycle equated to a dwell period of 30 s and a transfer time of 10 s in each temperature-controlled tub. The same measuring techniques were applied to all of the samples after thermocycling without success.

Surface hardness measurements

The Vickers hardness numbers (VHNs) for the tested bars were calculated using a Vickers microhardness tester (WILSON Microhardness machine, 500 Neton) (Fig. 4). A 50 g load was applied by the diamond indenter for a dwell time of 10 s. Five indentation readings were taken for each specimen, and the average of those readings was calculated. Then, for each group, surface hardness was assessed and statistically analyzed both before and after thermocycling was used to age the materials. A total of 5,000 cycles in the water bath (5–55°C, 30 s, and 10 s transfer time) were used to simulate sixth months of oral usage.

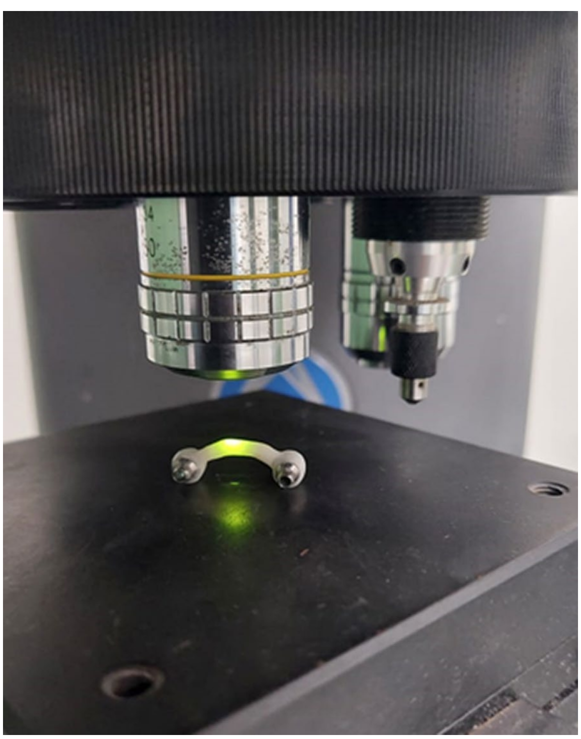

Fig. 4 Surface hardness measurement

Flexure strength measurements

A three-point bending test was used to test the flexural strength of the material. Two parallel stainless steel rods with a 50 mm span held the specimens in place. They were tested for maximum flexion or static compression using a universal testing machine (Model 3345; Instron Industrial Products, Norwood) with a load cell of 5 kN and a crosshead speed of 1 mm/minute until breakage. Utilizing computer software (Instron Bluehill Lite), the data were gathered. The force at which failure or instability is likely to occur is known as the fracture force and is expressed in Newtons (N). Using the following equation, the fracture strength (FS) was determined in MPa: FS(ó) = 3F(L)/2wh where L is the span, w is the specimen's width, and h is its height, and F is the maximum load in Newtons given to it.

Results

Sample size calculation

Based on a previous study (Porojan et al. 2022), sample size was calculated. If mean ± standard deviation of control group is 28.37 ± 0.77, while estimated mean of intervention group is 30, with effect size = 2.11, power (80%) and α error probability (0.05), minimally the study needed 5 subjects in each group (10 in both groups), total sample size increased to 6 subjects per group (12 in both groups) to compensate 15% drop out. Sample size was performed by using Independent t test by using G. power 3.1.9.7.

Statistical analysis

SPSS 16® (Statistical Package for Scientific Studies), GraphPad Prism, and Windows Excel were used to do the statistical analysis, which was reported in two tables and two graphs. Shapiro–Wilk and Kolmogorov–Smirnov tests for normality were used to examine the provided data, and the results showed that the data originated from normal data. As a result, a paired t test was used to compare before and after, whereas an independent t test was used to compare distinct groups. The significance level was set at $P \leq 0.05$.

Surface hardness

Effect of time (comparison between before and after thermocycling)

In PEEK group, there was insignificant decrease in surface hardness from (26.3 ± 0.14) before thermocycling to (24.5 ± 0.2) after thermocycling as $P = 0.51$, while in Acetal group there was a significant decrease in surface hardness from (23.63 ± 0.93) before thermocycling to (21.03 ± 0.21) after thermocycling as $P = 0.03$, as displayed in Table 1 and Fig. 5.

Table 1 Minimum, maximum, mean and standard deviation of before and after in both groups and comparison between before and after (effect of time)

	Minimum	Maximum	Mean	SD	*P* value
PEEK					
Before	26.2	26.7	26.30	0.14	0.51
After	24.3	24.7	24.50	0.20	
Acetal					
Before	23	24.7	23.63	0.93	0.03*
After	20.8	21.2	21.03	0.21	

M: mean, SD: standard deviation, MD: mean difference, SEM: standard error mean, CI: confidence interval, L: lower arm, U: upper arm

*Significant difference as $P<0.05$

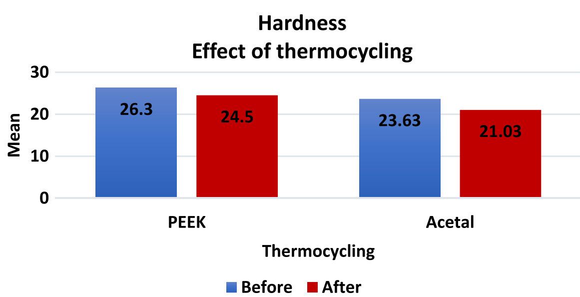

Fig. 5 Bar chart representing the effect of thermocycling on hardness in both groups

Table 2 Mean and standard deviation of before and after in both groups and comparison between both groups (effect of material)

	PEEK		Acetal		*P* value
	M	SD	M	SD	
Before	26.30	0.14	23.63	0.93	0.0001*
After	24.50	0.20	21.03	0.21	0.0001*

M: means, *Significant difference as $P<0.05$

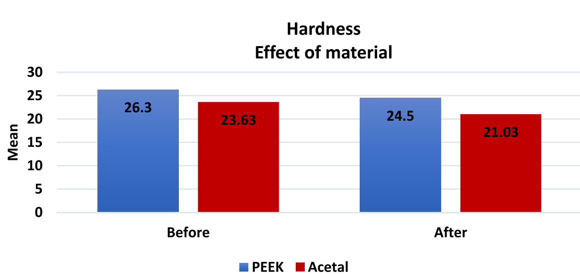

Fig. 6 Bar chart representing the effect of material on hardness before and after thermocycling

Effect of material (comparison between PEEK and Acetal)

Before thermocycling, PEEK (26.3 ± 0.14) revealed surface hardness significantly higher than Acetal (23.63 ± 0.93) as $P=0.00001$, while after thermocycling PEEK (24.5 ± 0.2) was a significant higher in surface hardness than Acetal (21.03 ± 0.21) as $P=0.0001$, as presented in Table 2 and Fig. 6.

Flexural strength

Effect of time (comparison between before and after thermocycling) In PEEK group, there was insignificant decrease in flexural strength from (90.41 ± 5.3) before thermocycling to (86.45 ± 4.5) after thermocycling as $P=0.28$, while in Acetal group there was a significant decrease in flexural strength from (87.3 ± 4.1) before thermocycling to (74.2 ± 3.5) after thermocycling as $P=0.002$.

Effect of material (comparison between PEEK and Acetal) Before thermocycling, PEEK (90.41 ± 5.3) revealed flexural strength insignificantly higher than Acetal (87.3 ± 4.1) as $P=0.28$, while after thermocycling PEEK (86.45 ± 4.5) was a significant higher in flexural strength than Acetal (74.2 ± 3.5) as $P=0.004$, as presented in Table 3 and Fig. 7.

Discussion

This study was designed to evaluate the mechanical properties of PEEK and Acetal resin bar attachment. The mechanical qualities of materials and their applicability for various applications are greatly influenced by their hardness. The material's hardness becomes a crucial factor when deciding between Acetal and PEEK (polyetheretherketone) bar attachments for overdentures. The null hypothesis was rejected as there was difference between the two study groups.

Our research indicates that when it comes to the impact of thermocycling, the surface hardness of the PEEK group decreased insignificantly before and after thermocycling, whereas the surface hardness of the Acetal group decreased significantly before and after thermocycling. Prior to thermocycling, PEEK's surface hardness was found to be much higher than Acetal when comparing the mechanical properties of the two thermoplastic materials. This result persisted after thermocycling.

In terms of the flexure strength of both bar materials, PEEK showed a higher result than Acetal at the base line before thermocycling, although the difference was insignificant. Acetal resin's flexure strength significantly decreased after thermocycling; however in the PEEK group, the effect of thermocycling had less of an impact.

Table 3 Flexural strength in both groups before and after thermocycling

Thermocycling	PEEK		Acetal resin		Difference				
	M	SD	M	SD	MD	SEM	95% CI		*P* value
							L	U	
Before	90.41	5.3	87.3	4.1	3.11	2.730	−2.980	9.2	0.280
After	86.45	4.5	74.2	3.5	12.25	2.320	7.060	17.43	0.004*
	0.28		0.002*						

*Significant difference as $P < 0.05$

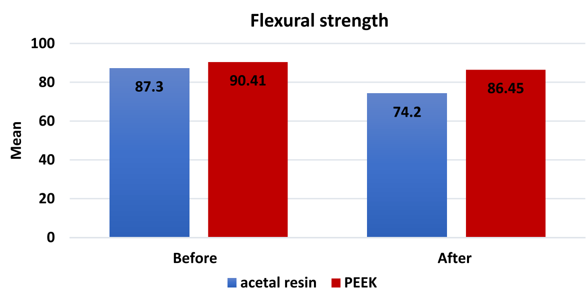

Fig. 7 Bar chart representing flexural strength of both groups before and after thermocycling

The PEEK group displayed much higher values than the Acetal group following the thermocycling, resulting in a significant difference between the two groups.

Thermocycling, which primarily involves changing the temperature and immersing objects in water under controlled laboratory circumstances, can be used as a technique for artificial aging. Thermal cycling is likely to cause microcracks, which increase surface roughness, water absorption and dissolution (Müller et al. 2017).

In agreement with our findings, Fathy et al. investigated the effect of thermocycling and discovered that although Acetal Resin clasps' surface microhardness greatly decreases; PEEK properties are not much affected. Mechanical properties of PEEK clasps were statistically considerably superior (Fathy et al. 2021).

PEEK material recorded statistically greater results than Acetal resin regarding retention and fatigue resistance. However, both materials, if appropriately constructed, will exhibit adequate mechanical qualities that can be employed in clinical settings (Elsegai and Abbas 2018).

Other contrasts include the flexural strength of PEEK and Acetal Resin. They discovered that PEEK has mechanical qualities that are statistically considerably higher than those of Acetal Resin. In general, it appears that PEEK has more flexural strength than Acetal Resin. However, the precise values may vary depending on a number of variables, including manufacturing conditions, processing parameters, and testing procedures (Fathy et al. 2021).

It is important to note that the increase in flexural strength values was directly correlated with the increase in the corresponding thicknesses, as it was found that the flexural strength increased by 20.18% for every 0.5 mm increase in thickness and by 48.39% for every 1 mm increase in thickness. With increasing thickness, Acetal samples flexural strength values significantly increased. These findings were consistent with our investigation since the Acetal resin bar's baseline flexure strength was strong due to the Acetal bar's proper thickness of more than 2 mm (Georgiev et al. 2018).

However, PEEK had noticeably better performance than Acetal resin following thermocycling. After thermocycling, the flexure strength of the Acetal resin significantly decreased. This can be explained by how humidity and aging have a negative impact on the mechanical characteristics of Acetal resin materials. According to a prior study, Acetal samples with a thickness of 2 mm failed to record adequate flexural strength in comparison with PEEK which recorded noticeably greater flexural strength values. This finding is consistent with current study's findings (Mohamed et al. 2021).

Both PEEK and Acetal Resin exhibit commendable flexural strengths, thanks to their unique properties and characteristics. While PEEK generally presents greater flexure strength due to its highly crystalline structure and molecular alignment, Acetal Resin also demonstrates satisfactory resistance to bending forces. Accurate assessment, considering various factors, such as manufacturing conditions, processing parameters, and testing methodology, becomes imperative when comparing their flexural performances.

Conclusions

The following conclusions can be made in light of our study:

1. The surface hardness and flexure strength of PEEK bars were clinically acceptable and superior to Acetal bars. However, both thermoplastic materials and adequately designed bars might be enough for clinical use.
2. Bars made of PEEK showed a more promising surface hardness and flexural strength even after the thermocycling effect.

Abbreviations

PEEK	Polyetheretherketone
CAD/CAM	Computer-aided design/computer-aided manufacturing
VHN	Vickers hardness numbers
Co-Cr	Cobalt-chrome
SPSS	Statistical Package for Scientific Studies

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Not applicable.

Author contributions
S.H., A.A. and M.H. conducted the laboratory procedures, data collecting, statistical analysis, and manuscript preparation. The authors evaluated and approved the final version of the paper.

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Availability of data and materials
The corresponding author will provide the datasets created and/or analyzed for the current work available upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the ethical committee of the faculty of oral and dental medicine at Ahram Canadian University, No IRB00012891#59.

Consent for publication
Not applicable.

Recommendation
To validate these laboratory findings, additional clinical research was advised.

Competing interests
The authors declare that they have no competing interests.

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