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Fatigue resistance and flexural behavior of acetal resin and chrome cobalt removable partial denture clasp: An *in vitro* study

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ABSTRACT

Statement of Problem: The denture clasp undergoes fatigue on the repeated deflection of the clasp during insertion and removal of the removable partial denture over the undercuts of the teeth. This study was conducted to know how acetal resin functions in this application. **Aims:** The purpose of the study was to evaluate fatigue resistance of acetal resin clasps subjected to repeated constant deflections and compare it with cobalt-chromium clasp. **Materials and Methods:** Acetal resin and Co-Cr clasp specimens were subdivided (n = 10) specimens to perform deflection of 0.25 mm and 0.50 mm. Constant load for deflection of either 0.25 or 0.50 mm was applied to 2 mm from the point of the clasp at the appropriate loading frequency assuming that the clasps were inserted and removed from the abutment with undercut of either 0.25 mm or 0.50 mm. The fatigue test was carried out until 10^6 cycles or until permanent deformation detected. The data obtained were subjected to unpaired t-test. **Results:** It was observed that the deformation of chrome cobalt clasp specimen during the loading cycle of 10^6 under deflection of 0.5 mm was 0.1530 ± 0.0177 mm. Chrome cobalt clasp under 0.25 mm deflection and an acetal resin specimen under 0.25 and 0.5 mm deflection did not show any significant deformation. **Conclusions:** The clasp with acetal resin may provide less retention than cobalt chromium-based alloys. For acetal resin clasp, no permanent deformation was detected after 10^6 loading cycles when deflected to 0.25 mm and 0.5 mm and has mean flexural strength of 72.436 MPa and modulus of elasticity of 2.245 GPa.

KEYWORDS: Acetal, clasp, deformation, esthetic, fatigue, removable partial denture

Introduction

The use of metal clasps on anterior teeth may cause esthetic problems. Fabricating an esthetically pleasing removable partial denture (RPD) while avoiding the unsightly display associated with conventional clasp assemblies often presents a challenge to dentists. Methods to overcome this esthetic dilemma have included the painting of clasps with tooth-colored resin, use of lingually positioned clasps, engagement of mesial rather than distal undercuts, and use of gingival rather than occlusally approaching clasps. Unless clasps can be avoided by using precision attachments, which are relatively expensive and technically demanding, some of the RPD framework will invariably be visible.[1]

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Usage of thermoplastic resin in dentistry has significantly grown in the last decade. The technology is based on plasticizing the material using only thermal processing in the absence of any chemical reaction.[2] Thermoplastic processing implies using complete polymerized or prepolymerized resins. These materials are presented as grains, with low molecular weight (150,000). They have low plasticizing temperature and exhibit high rigidity in spite of low molecular weight.[3]

Polyoxymethylene (POM), which is formed by polymerizing formaldehyde, may be used as an alternative denture clasp material. The homopolymer, POM is a chain of alternating methyl groups linked by an oxygen molecule. Acetal as a homopolymer has good short-term mechanical properties, but as a co-polymer has better long-term stability.[4] The material has been shown to have good biocompatibility and this has fostered its use in total hip replacement and as artificial heart valve occluders.

Acetal resin is very strong, resists wear and fracture, and is quite flexible. They also exhibit high creep resistance and high fatigue endurance as well as hydrophobicity, which mean that the material will not absorb water or saliva. They are monomer free and offer an innovative and safe treatment alternative for patients who are allergic to conventional resins. They have little or no porosity, which reduces the accumulation of biological material like plaque and it also resists odor and stains.[5]

For a clasp in RPD, the stresses encountered should be below that limit to prevent plastic deformation of the clasp in function. The fatigue of a denture clasp is based on the repeated deflection of the clasp during insertion and removal of the RPD over the undercuts of the teeth.[6] Although extensive work has been performed to determine the properties of a variety of materials used for RPD clasps,[7-10] little is known about how acetal resin functions in this application. The purpose of the study was to evaluate fatigue resistance of acetal resin clasps subjected to repeated constant deflections corresponding to the undercut when these are used as the clasp material and compare it with cobalt-chromium clasp. The flexural strength, Young's modulus of acetal flexural specimen under three-point bending test was also evaluated.

Materials and Methods

In this study, 20 acetal resin clasps and 20 cobalt chromium clasps and 10 acetal rectangular specimens were used. For chrome cobalt clasp, preformed half round standard (0.8 mm) wax pattern were invested according to manufacturer's instruction and cast in Co-Cr alloy. The clasp were trimmed, airborne particle abraded, finished, and electropolished using a standardized procedure. Acrylic dies of dimensions 64 mm long, (10 ± 0.2) mm wide and (3.3 ± 0.2) mm in heights were fabricated by laser cutting. For the fabrication of clasp, specimen prefabricated half round wax profiles (0.8 mm) diameter was used. Sprues were attached using a 2.5 mm Biotech wax pattern and connected to form a main channel (resin sprue wax). It was then flasked using an aluminum flask then clamped. Once the dental stone had completely set, boiling out was done. All the screws of the flask were removed prior to boiling out. After boiling, the acrylic dies were removed and any remnants of wax were removed with hot water rinse. Acrylic Sep separating medium was applied once on the hot stone surface. Highly lustrous surface was obtained through previous sealing of the stone surface with die varnish. Then the flasks were kept inside the ultraviolet curing unit for 10 min. Cartridge had been previously coated with high-temperature grease. Measured amount of acetal resin material was loaded in the cartridge and inserted into the heating chamber. According to manufacturer's instructions, acetal resin material was preheated at a processing temperature of 220°C for 15 min. Injection process was done at 7.2–7.5 bar pressure for 0.25 s. The pressure was maintained in the unit for 1 min so that the material gets hardened under pressure to compensate any shrinkage. The flask was divested after a cooling phase of approximately 25 min. After deflasking, the edges of the rectangular clasps specimens were smoothened with tungsten carbide bur followed by abrasion with 600 grit sandpaper to the final dimensions of 64 mm × 10 mm × 3.3 mm length, width and thickness respectively and half round clasp specimen of 0.8 mm diameter. The surface was then finished and polished using pumice and muslin buffing wheel.

Acetal resin and Co-Cr clasp specimens were subdivided (n = 10) specimens to perform deflection of 0.25 mm and 0.50 mm. Clasp specimens were divided into flowing groups.

- Group WA-Cr-Co clasp specimen (n = 10) were deflected to 0.25 mm.
- Group AA-Acetal resin clasp specimen (n = 10) were deflected to 0.25 mm.
- Group WB-Cr-Co clasp specimen (n = 10) were deflected to 0.5 mm.
- Group AB-Acetal resin clasp specimen (n = 10) were deflected to 0.5 mm.

Constant load for deflection of either 0.25 or 0.50 mm was applied by a to 2 mm from the point of the clasp at the appropriate loading frequency assuming that the clasps were inserted and removed from the abutment with undercut of either 0.25 mm or 0.50 mm. Instron machine (The Nano Plug "n" Play of 6 kHz digital servo control, 25-bit data acquisition, BISS, India, Bangalore) to the deflection fatigue test. A fixture is attached to apply specific load on to the clasp tip. The fatigue test was carried out until 10^6 cycles or until permanent deformation was detected. The data obtained were subjected to unpaired t-test.

For the evaluation of flexural strength, three measurements of the rectangular specimen were made along the long axis with an accuracy of ± 0.01 mm using a digital vernier calliper. The deviation between the three measurements along the long axis was not more than ± 0.02 mm. The specimens were flat and had an even height. The rectangular specimens were immersed in Petri dish containing water at a temperature of (37°C ± 1°C) for (50°C ± 2°C) h prior to flexural testing. Three-point bending test was carried out with a universal testing machine (The Nano Plug "n" Play of 6 kHz digital servo control, 25-bit data acquisition, BISS, India, Bangalore) (in air) at room temperature. The specimen strip was taken from water storage and immediately laid the flat surface symmetrically on the supports of the flexural test rig. The load was applied to the center of the flexural specimen at a loading rate of 0.5 N/s. Loading was continued until the flexural specimen fracture and maximum load sustained was measured and Young's modulus was also calculated.[11]

The ultimate flexural strength was calculated using the following equation in megapascals

$\sigma = 3Fl/2bh^2$

Where
F is the maximum load, in Newtons, extended on the specimen;
l is the distance, in millimeters, between the supports, accurate to ± 0.01 mm;
b is the width, in millimeters of the specimen measured immediately prior to water storage;
h is the height, in millimeters, of the specimen measured immediately prior to water storage.

The flexural modulus was calculated by using the following equation in megapascals.

$E = F_1 l^{3}/4bh^3 d$

where
F_1 is the load, in newtons, at a point in the straight line portion (with the maximum slope) of the load/deflection curve;
d is the deflection, in millimeters, at load F_1;
l is the distance, in millimeters, between the supports, accurate to ± 0.01 mm;
b is the width, in millimeters of the specimen measured immediately prior to water storage;
h is the height, in millimeters, of the specimen measured immediately prior to water storage.

Results

The mean load required to deflect the clasp to 0.25 mm is higher for chrome cobalt (WA) 0.6440 ± 0.0655 Kgf as compared to acetal resin clasp (AA) 0.2130 ± 0.0221 Kgf [Tables 1 and 2].

The flexibility of acetal resin clasp bar under 0.25 mm deflection is higher for acetal resin (AA) 1.1790 ± 0.1169 mm/Kgf as compared to chrome cobalt clasp (WA) 0.3870 ± 0.0452 mm/Kgf [Tables 1 and 2].

The mean load required to deflect the clasp to 0.5 mm is higher for chrome cobalt (WB) 1.6270 ± 0.1254 Kgf as compared to acetal resin clasp (AB) 0.4330 ± 0.0392 Kgf [Tables 3 and 4].

The flexibility of acetal resin clasp bar under 0.5 mm deflection is higher for acetal resin (AB) 1.1570 ± 0.0966 mm/Kgf as compared to chrome cobalt clasp (WB) 0.3030 ± 0.0231 mm/Kgf.

It was observed that the mean deformation of chrome cobalt clasp specimen under deflection of 0.5 mm was 0.1530 ± 0.0177 mm [Table 5]. Chrome cobalt clasp under 0.25 mm deflection and an acetal resin specimen under 0.25 and 0.5 mm deflection did not show any significant deformation. The mean flexural strength of acetal resin is 72.436 MPa and modulus of elasticity of 2.245 GPa [Table 6].

Discussion

This study was designed to compare flexural behavior of clasp when subjected to deflection of 0.25 mm and 0.5 mm at appropriate loading frequency assuming that clasps were inserted and removed from the abutment undercut of either 0.25 mm or 0.5 mm. The 0.25 mm undercut was selected because it represents the undercut commonly used for

Table 1: Mean and SD of the values of load required to deflect the clasps to 0.25 mm and the flexibility of the clasps

Variable	Group	Mean	SD*
Load required to deflect the clasps to 0.25 mm (Kgf)	WA†	0.6440	0.0655
	AA††	0.2130	0.0221
Flexibility of clasp (mm/Kgf)	WA	0.3870	0.0452
	AA	1.1790	0.1169

The mean load required to deflect the clasp to 0.25 mm is higher for chrome cobalt (WA) 0.6440±0.0655 Kgf as compared to acetal resin clasp (AA) 0.2130±0.0221 Kgf, the flexibility of acetal resin clasp bar under 0.25 mm deflection is higher for acetal resin (AA) 1.1790±0.1169 mm/Kgf as compared to chrome cobalt clasp (WA) 0.3870±0.0452 mm/Kgf. †WA-Cr-Co clasp specimen (n=10) which were deflected to 0.25mm, ††AA-Acetal resin clasp specimen (n=10) which were deflected to0.25 mm. 1*SD = Standard deviation

Table 2: Statistical pairwise comparison (unpaired *t*-test) of the mean values of deflection of the tapered half round wire cast in Wironit and acetal resin

Variable	Group	Mean	SD	*t**	*P*†
Load required to deflect the clasps to 0.25 mm (Kgf)	WA	0.6440	0.0655	19.7066	0.0000[a]
	AA	0.2130	0.0221		
Flexibility of clasps (mm/Kgf)	WA	0.3870	0.0452	−19.9741	0.0000[a]
	AA	1.1790	0.1169		

[a]Significant at 5% level of significance (P<0.05), *t-absolute t-value, †P-Probability. The t value for load was found to be 19.707 and P=0.000 and for flexibility t value was −19.974, P=0.000. SD = Standard deviation

Table 3: Mean and SD of the values of load required to deflect the clasps to 0.5 mm and the flexibility of the clasps

Variable	Group	Mean	SD
Load required to deflect the clasp to 0.5 mm (Kgf)	WB††	1.6270	0.1254
	AB§	0.4330	0.0392
Flexibility of clasps (mm/Kgf)	WB	0.3030	0.0231
	AB	1.1570	0.0966

The mean load required to deflect the clasp to 0.5 mm is higher for chrome cobalt (WB) 1.6270±0.1254 Kgf as compared to acetal resin clasp (AB) 0.4330±0.0392 Kgf. The flexibility of acetal resin clasp bar under 0.5 mm deflection is higher for acetal resin (AB) 1.1570±0.0966 mm/Kgf as compared to chrome cobalt clasp (WB) 0.3030±0.0231 mm/Kgf. ††WB-Cr-Co clasp specimen (n=10) which were deflected to 0.5mm, §AB-Acetal resin clasp specimen (n=10) which were deflected to 0.5 mm. SD: Standard deviation

Co-Cr clasps. With the increased requirements of esthetics, more patients are requesting that dentists to conceal RPD clasps by placing them closer to the gingiva, where the undercuts tend to be larger. The stiffness of Co-Cr clasp makes them unsuitable for placement in larger undercuts due to unacceptable stresses on the abutments.[9] During function, the clasp arm is deflected outward when inserted in mouth and inward when removed and stresses are developed within the alloy.[12] One property of acetal resins that has created interest for use in RPD is the low modulus of elasticity, which allows for their use in larger retentive undercuts than recommended for Co-Cr alloys.[1,4] This may be advantageous in a clinical situation in which esthetics and/or periodontal health are priorities.[10,13] The deflection to 0.5 mm is chosen to determine whether fabrication of clasps from acetal resin would be a possible alternative to the metal clasp in larger undercuts. As the length of the clasp increases and its cross sectional area decreases,the flexibility of a clasp increases,thereby reducing transmission of lateral forces on the abutment teeth.[14] The properties of clasp vary considerably i accordance with the specific metal or alloy used.[15] However, it was studied that clasp length in clinical cases, is usually between 8 and 12 mm. When compared at 8 or 12 mm lengths, the difference in thickness is somewhat less than that found at the 18 mm length.[16] Hence, clasp length of 12 mm were used in our study. Several studies of the fatigue strength of cobalt-chromium alloys have reported fatigue limits from 40,000 psi to 70,000 psi.[17] Therefore, number of loading cycle was kept at 10^6 in our study. The loading frequency of 20 Hz was used which is higher than the reported chewing rate (1–2 Hz).[18]

Table 4: Statistical pairwise comparison (unpaired t-test) of the mean values of deflection of the tapered half round wire cast in Wironit and acetal resin

Variable	Group	Mean	SD	*t*	*P*
Load required to deflect theclasps to 0.5 mm (Kgf)	WB	1.6270	0.1254	28.7324	0.0000[a]
	AB	0.4330	0.0392		
Flexibility of clasps (mm/Kgf)	WB	0.3030	0.0231	−27.1846	0.0000[a]
	AB	1.1570	0.0966		

[a]Significant at 5% level of significance ($P<0.05$), The *t* value for load was found to be 28.732 and $P=0.000$ and for flexibility *t* value was −27.185, $P=0.000$. SD: Standard deviation

Table 5: Means (SD) of fatigue test

	Preset deflection (mm)	Material	
		Cr-Co	Acetal resin
Test group code/ number of specimen	0.25	WA/10	AA/10
	0.50	WB/10	AB/10
Cycles 10^6	0.25	No deformation	No deformation
	0.50	0.1530±0.0177	No deformation

It was observed that the mean deformation of chrome cobalt clasp specimen under deflection of 0.5 mm was 0.1530±0.0177 mm. Chrome cobalt clasp under 0.25 mm deflection and an acetal resin specimen under 0.25 and 0.5 mm deflection did not show any significant deformation. SD = Standard deviation

With this study design the force required to deflect to 0.25 mm and 0.5 mm closely related to the retention magnitude of the material under these 2 undercuts. The mean load required to deflect the chrome cobalt clasps were comparatively higher to acetal resin when subjected to deflection of 0.25 mm and 0.5 mm. Whereas, the flexibility was higher for acetal resin clasp compared to chrome cobalt. This may indicate that the clasp with acetal resin may provide less retention as compared to cobalt chromium-based alloys; however, it is beneficial, as such clasp, for a given undercut, would exert less stresses on to the abutments and thereby preserve the health of periodontium.

Ahmad, Sherrif, and Waters found that 4.77 N was required to dislodge a cobalt chromium clasp from 0.25 mm undercut. Frank *et al*. concluded that 300–750 g (2.9–7.4 N) represented an acceptable amount of retention for bilateral distal extension RPD.[17] Turner *et al*.[1] suggested that in clinical use, acetal resin clasp should have a shorter length, relatively larger cross-sectional area, and engage deeper undercuts to have adequate retention. It could be argued that a larger, bulkier clasp design would be detrimental to oral health by contributing to plaque accumulation. In our study, we found that the flexibility of acetal resin (elastic modulus; 2.9–3.5 kN/mm^2) when compared to chrome cobalt alloy (elastic modulus; 22.43 kN/mm^2) was more. Fitton *et al*.[4] stated that to gain adequate retention from acetal resin clasps the clasps should have greater cross-sectional area than the metal clasp. But in our study, we have used same diameter for standardization. The results in our study refer to straight specimens, but the curvature and taper influences the stiffness of the material. When subjected to fatigue test it was observed that chrome cobalt clasp under 0.25 mm deflection and an acetal resin specimen under 0.25 and 0.5 mm deflection did not show any significant deformation. However, the deformation of chrome cobalt clasp specimen during the loading cycle of 10^6 under deflection of 0.5 mm was 0.1530 ± 0.0177 mm. VandenBrink *et al*.[19] compared certain physical properties of various RPD direct retainers, including thermoplastic materials (Flexite M.P. and Flexite II,) injection – moulded into rectangular beams. The authors found no significant difference in the stiffness or proportional limit for direct retainers fabricated in these thermoplastic materials from their metal counterparts. The

Table 6: Flexural strength and modulus of elasticity of acetal resin

	Mean	SD	Co-efficient of variation	Minimum	Maximum	Range
Flexural strength (MPa)	72.436	2.297	0.032	68.422	76.085	7.662
Maximum load (*n*)	103.400	7.457	0.072	92.000	112.000	20.000
Modulus of elasticity (GPa)	2.245	0.106	0.047	1.976	2.332	0.356

The mean flexural strength of acetal resin is 72.436 MPa and modulus of elasticity of 2.245 GPa. SD = Standard deviation investigation differed from the present study as the direct retainers were deflected only once in 0.125 mm increments up to and beyond the proportional limit, rather than subjected to repeated stress.

Cheng *et al*.[20] showed that the mean value of displacement at proportional limit for the three Co-Cr alloy (Hardalloy, Regalloy, and Vera PDN) varied from 0.30 to 0.36 mm and compared to clasps in the 0.25 mm undercut groups, those in the 0.5 mm undercut group exhibited greater mean retentive forces before the cyclic fatigue test as well as a greater decrease in the retentive force at the end of the test.

Bates[21] showed that a 10 mm long Cr-Co clasp would display tip deflection of 0.15 mm at proportional limit. Morris *et al*.[16] suggested that permanent deformation of clasp tip by > 0.025 mm may be significant. The results of the present study showed significant deformation of chrome cobalt clasps when subjected to cyclic loading 10^6 under 0.5 mm deflection. However, acetal resin clasp showed no significant deformation in either 0.25 mm or 0.5 mm deflection when subjected to cyclic loading of 10^6 at 20 Hz.

Flexural tests are probably the tests with the greatest direct clinical relevance in that they assess the manifestation of complex stresses which occur in use. Rectangular flexural specimens were subjected to three-point bending test where the load is applied to the center of the flexural specimen at a loading rate of 0.5 N/s until the flexural specimen fracture and maximum load sustained will be measured and Young's modulus will be also calculated. It was found that acetal resin has mean flexural strength of 72.436 MPa and modulus of elasticity of 2.245 GPa. Other properties of acetal resin need to be studied to use it as a framework of RPD.

It was considered more practical to conduct the study in laboratory (*in vitro*), as it is not practical and feasible to calculate the insertion and removal, size, and degree of undercuts variation, and standardization of length of retentive arm in patient's mouth. Specialized equipment required to make acetal resin clasp specimen is one of the disadvantages to use as an esthetic clasp material.

Limitations of the study

Relatively small sample sizes (40) were used and each group had only 10 samples. A study on curved clasp – arm was not included. Precision in load measurement is questionable. There would have been variations due to intraoperative sensitivity and variability. The ultimate test for any research conclusion is its application to patient and the final evaluation in the oral cavity which not considered.

Further scope of the study

Activation of the clasp and the other parameters which include the external medium such as saliva and water on various physical properties and microstructure of the clasps on functional loading could be interesting. Further study using deeper undercuts and thicker retentive clasp arms should be recommended to provide additional information regarding the use of acetal resin clasp. Use of acetal resin in RPD framework has to be further studied.

Conclusion

Within the limitations of this study, it was concluded that the mean load (Kgf) required for deflecting the clasp of chrome cobalt is comparatively higher than acetal resin. The flexibility (mm/Kgf) values are more with regard to acetal resin clasp specimen compared to chrome cobalt when deflected to 0.25 mm and 0.5 mm undercuts. This may indicate that the clasp with acetal resin may provide less retention than cobalt chromium-based alloys; however, it is beneficial, as such clasp, for a given undercut, would exert less stresses on to the abutments and thereby preserve the health of periodontium. For acetal resin clasp, no permanent deformation was detected after 10^6 loading cycles when deflected to 0.25 mm and 0.5 mm. Whereas, chrome cobalt clasp under 0.25 mm deflection showed no deformation, 0.5 mm deflection showed significant deformation of 0.1520 mm. It was found that acetal resin has mean flexural strength of 72.436 MPa and modulus of elasticity of 2.245 GPa.

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