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Retentive forces and fatigue resistance of thermoplastic resin clasps

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ABSTRACT

Objectives. The objective of this study was to evaluate the retentive force of clasps made from three thermoplastic resins and cobalt–chromium (CoCr) alloy by the insertion/removal test simulating 10 years use.

Methods. On standardized premolar metal crowns 112 clasps were fabricated, including 16 CoCr (1.0 mm thick) clasps and 32 clasps (1.0 or 1.5 mm thick) from each of the following thermoplastic resins: polyetheretherketon (PEEK), polyetherketonketon (PEKK) and polyoxymethylene (POM). Specimens were divided in subgroups with clasp undercuts of 0.25 mm and 0.5 mm, respectively. Each clasp assembly was subjected to an insertion/removal test on its abutment crown for 15,000 cycles. To analyze the retention over the course of insertion/removal test, retention was measured every 1500 cycles. Data were statistically analyzed using 3-way ANOVA ($\alpha = 0.05$).

Results. Resin clasps with 1.5 mm thickness showed higher retention (4.9–9.1 N) than clasps with 1.0 mm thickness (1.2–3.1 N; $P \leq 0.001$). Resin clasps of both dimensions had significantly lower retentive force than CoCr clasps (11.3–16.3 N; $P \leq 0.001$). Clasps with 0.25 mm undercut showed significantly less retention than clasps with 0.50 mm ($P \leq 0.001$). All clasps exhibited an increase in retentive force during the first period of cycling followed by continuous decrease till the end of the cycling but it was still significantly not different compared to the initial retentive force ($P = 0.970$).

Significance. Thermoplastic resin clasps maintained retention over 15,000 joining and separating cycles with lower retention than CoCr clasps. However, the retention of adequately designed resin clasps might be sufficient for clinical use.

1. Introduction

The emphasis on physical appearance in contemporary society has increased the demand for esthetic dental restorations. Although the success of implant dentistry has expanded the scope of esthetic fixed prostheses, there are still many patients who for health, anatomic, psychological, or financial reasons are not candidates for implants [1]. These patients have the option of receiving partial removable dental prostheses (PRDPs) to replace missing teeth.

A major esthetical problem with PRDPs is the display of the clasp assemblies. Many methods have been used to overcome the esthetic problem such as etching the clasp arm and coat it with a layer of tooth-color resin [2], using lingual retention design [3], or proximal undercuts (also known as rotational path insertion) [4–6].

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Table 1 – Materials used for clasp fabrication.

Brand name	Composition	Manufacturer	Batch number
Acetal Dental	Polyoxymethylene (POM)	Dental Srl, San Marino, Italy	01065
Bio XS	Polyetheretherketon (PEEK)	Bredent, Senden, Germany	540XS016901
PEKKtone A	Polyetherketonketon (PEKK)	Cendres Metaux, Bienne, Switzerland	X1074M
Wironit	Co 64%; Cr 28.6%; Mo 5% (CoCr)	Bego, Bremen, Germany	12769

Direct retainers fabricated in a tooth-colored material and made from thermoplastic resin have been used to improve the appearance of metal clasp assemblies and are promoted for superior esthetics [7–9]. However, little information on the long-term performance of such clasps regarding retention is available in the literature.

Polyetheretherketon (PEEK) and polyetherketonketon (PEKK) are polymers from the group polyaryletherketone (PAEK) which is a relatively new family of high-temperature thermoplastic polymers, consisting of an aromatic backbone molecular chain, interconnected by ketone and ether functional groups [10]. In medicine PAEK has been demonstrated to be excellent substitute for titanium in orthopedic applications [10,11], and it has been used in dentistry as provisional implant abutment [12].

Polyoxymethylene (POM) also known as acetal resin, an injection-molded resin has been introduced as an alternative to conventional PMMA. POM is formed by the polymerization of formaldehyde. The homopolymer, polyoxymethylene is a chain of alternating methyl groups linked by an oxygen molecule. It has a relatively high proportional limit with little viscous flow enabling it to behave elastically over a great enough range to be used as a material for clasp construction [7].

Various metallic materials have been used to fabricate the clasps of PRDPs and the physical properties of these materials have been examined [13–23]. The most common alloys used for clasps are cobalt–chromium (CoCr) alloys [21]. There have been studies that investigated the retention properties of CoCr alloys using repeated insertion/removal tests. Rodrigues et al. indicated an increase in retentive force during the simulating test [16], while retention decrease was reported by both Bridgeman et al. [20] and Kim et al. [24].

Retentive clasp arms must be flexible and should retain the PRDP satisfactorily. In addition, clasps should not unduly stress abutment teeth or be permanently distorted during service [25]. Previous studies indicated that PRDP clasps made of more elastic materials demonstrated a higher resistance to retention loss [24,25].

Due to the low modulus of elasticity (2–4 GPa) (Table 3) [8,10], thermoplastic resin has superior flexibility compared to the conventional CoCr alloys. Because of the reduced possibility of traumatic overloading, clasps made from thermoplastic resin can be designed to engage deeper undercuts on abutment teeth.

There are few studies that examined flexural properties of POM to determine the appropriate design for PRDP clasp [7,8]. Arda and Arikan found that POM clasps are resistant to deformation and may offer a clinical advantage over conventional metal clasps [9]. However, to our best knowledge there are no studies evaluating the use of PEEK and PEKK as clasp materials.

Therefore, this in vitro study investigated the retentive force of different thermoplastic resin clasps during repetitive placement and removal on abutment teeth with two different thicknesses and two amounts of undercut. Conventional CoCr clasps were included as control group. The null hypothesis was that there would be no difference in the retentive force between resin clasps and cast CoCr alloy clasps.

2. Materials and methods

Three thermoplastic resins (POM, PEEK and PEKK) and a conventional CoCr alloy were evaluated in this study.

All used materials are presented in Table 1.

2.1. *Abutment fabrication*

An artificial maxillary first premolar (KaVo, Biberach, Germany) was embedded in auto-polymerizing acrylic resin (Technovit 4000; Heraeus-Kulzer, Wehrheim, Germany) using custom-made copper holders with a diameter of 15 mm.

The maxillary first premolar was prepared for a surveyed complete metal crown. The prepared premolar was duplicated twice using a polyether impression material (Impregum Penta H and L; 3M Espe, Seefeld, Germany). The impressions were poured in Type IV stone (GC Fujirock EP; GC, Leuven, Belgium), and a complete crown was waxed on each preparation (Crowax; Renfert GmbH, Hilzingen, Germany).

The waxed crowns were surveyed to provide an undercut of 0.25 mm on one crown and 0.50 mm on the other. Occlusal rests, 2.5 mm long, 2.5 mm wide, and 2 mm deep, were placed mesially. Mesial and lingual guide planes, two thirds the length of the crown, were prepared with a surveyor blade to standardize the path of insertion. The waxed 2 crowns were duplicated with silicon material (Speedy Wax Transpaduplisil 101; Zahntechnik Norbert Wichnalek, Augsburg, Germany), and then 16 crowns with 0.25 mm undercut and 16 with 0.50 mm undercut were made by inserting heated liquid wax (Speedy Wax Injektionswachs 70; Zahntechnik Norbert Wichnalek) into the silicone mold. Then the crowns were cast in CoCr alloy (Wironit 99; Bego, Bremen, Germany).

After fitting and finishing, the crowns were cemented in place on the abutments with zinc phosphate cement (Hoffmann quick setting, Hoffmann, Berlin, Germany). The guide planes were evaluated for parallelism.

2.2. *Clasp fabrication*

To standardize the position of clasp arm undesirable undercut areas were blocked out with the sculpturing wax (Crowax, Renfert, Hilzingen, Germany) with approximately 2 mm surrounding thickness. Impressions of each model were made

Table 2 – Injection parameters for thermoplastic resin clasps.[a]

	POM	PEEK	PEKK
Pre-heating temperature/time	100/30 min	200/20 min	150/30 min
Melting temperature	220 °C	380 °C	325 °C
Pre-injection time	20 min	25 min	20 min
Injection pressure	4 bar	4 bar	7 bar
Post-injection time	5 min	2 min	1 min
Cooling time	60 min	60 min	60 min
Injection device	J-100; Pressing Dental Srl, San Marino, Italy	Thermopress 400 injection molding system; Bredent	Thermopress 400 injection molding system; Bredent

[a] According to the manufacturers.

in polyether impression material (Impregum Penta H and L) with custom impression trays. Each impression was poured with die-investment material (Obtivest, DeguDent, Hanau, Germany) to make a refractory cast for the CoCr clasps and, with Type IV dental stone (GC Fujirock EP, GC), to make refractory casts for the thermoplastic resin clasps.

For CoCr clasps, preformed half-round tapered clasp patterns (1 mm × 1.4 mm tip) with occlusal rests, and retentive and reciprocal arms (Wachsprofile, Bego) were adapted along the ledges formed with block-out material prior to making impressions. A round wax sprue was connected to the residual ridge base parallel to the path of insertion using a surveyor. This sprue was later used to maintain clasp test specimens in the masticatory simulator. Each assembly (die and pattern) was invested (Obtivest, DeguDent) according to the manufacturer's instructions and cast in CoCr alloy. Finally the clasps were trimmed, airborne-particle abraded with 50 μm alumina at 0.25 MPa pressure.

For fabrication of the 1.0 mm and 1.5 mm thick thermoplastic resin clasps straight semicircular clasp patterns (Wax patterns, Omnident, Rodgau Nieder-Roden, Germany) (1 mm × 2 mm and 1.5 mm × 3 mm) were used. The previously described wax sprue was connected to the residual ridge base parallel to the path of insertion using a surveyor. The parameters for the injection procedures have been set according to the manufacturers (Table 2).

Eight clasps were fabricated for each material, clasp size, and retentive undercut combination. A total of 112 clasps were made, including 16 CoCr clasps as control group.

2.3. *Testing conditions*

To perform the retention test, a masticatory simulator (Willytec, Munich, Germany) was used. The machine allows the placement of the clasp to its predetermined terminal position and its subsequent removal from the abutment crown, thus simulating the placement and removal of a PRDP. The models with the crowns were mounted in the masticatory simulator. Each clasp specimen was then placed on the corresponding abutment crown and fixed to the upper part of machine with auto-polymerizing acrylic resin (Technovit 4000, Heraeus-Kulzer) (Figs. 1 and 2). The test conditions were maintained at room temperature (20 ± 2 °C) and wet condition (deionized water). To analyze the data obtained during the simulation test, intervals every 1500 cycles were established. A total of 15,000 cycles were performed, representing the simulated insertion and removal of the PRDP over 10 years, estimating that the patient would perform four complete cycles per day. The test was performed at a constant speed of 8 mm/s. The value established for each time interval corresponded to the arithmetic average of 10 consecutive insertion/removal cycles. The force required for each specimen removal was captured and stored using data acquisition software (LabView, National Instrument, Munich, Germany). Statistical analysis was done with three-way analysis of variance (ANOVA). The significance level was set at 5% ($\alpha = 0.05$).

Table 3 – Mechanical properties of the materials used for clasp fabrication.[a]

	Modulus of elasticity	Tensile strength
POM	2.4 GPa	55 MPa
PEEK	4 GPa	97 MPa
PEKK	4 GPa	89 MPa
CoCr	211 GPa	880 MPa

[a] According to the manufacturers.

3. Results

Figs. 3 and 4 show the changes in retentive force required to remove clasps from the 0.25 mm and 0.50 mm undercuts.

The mean initial retentive force ranged from 1.2 to 3.1 N for the 1.0 mm thick resin clasps and from 4.9 to 9.1 N for

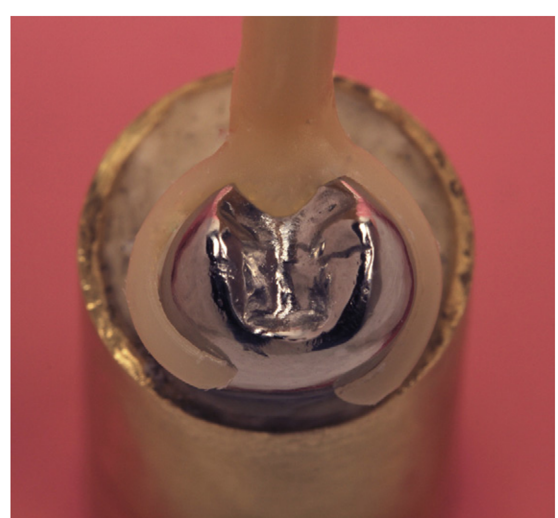

Fig. 1 – Resin clasp on abutment crown.

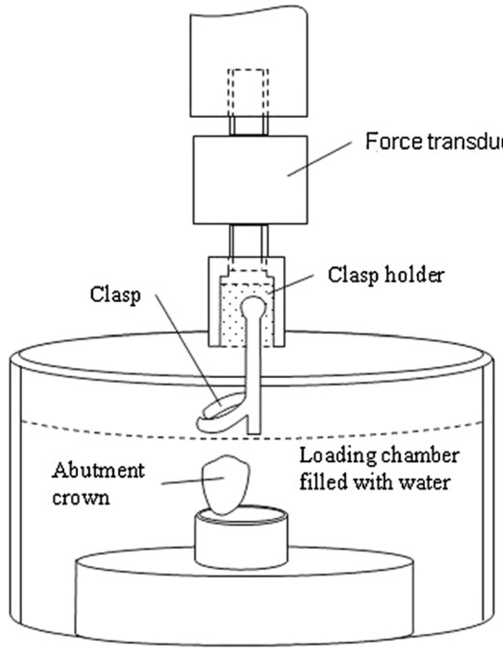

Fig. 2 – Schematic illustration of the assembly (clasp-abutment crown) mounted in the loading chamber.

the 1.5 mm thick resin claps. For CoCr clasps it ranged from 11.3 to 16.3 N. The highest initial retentive force (16.3 N) was recorded in the CoCr clasps with 0.50 mm undercut, and the lowest retentive force (1.2 N) was measured in the 1.0 mm POM clasps with 0.25 mm undercut.

Results of the three-way ANOVA for the resin clasps indicated a significant influence of the three tested factors on the retention at the first period of the cycling ($P \leq 0.001$). PEEK exhibited the highest retention followed by PEKK and POM ($P \leq 0.001$). As well the retentive force required to dislodge 1.5 mm thick resin clasp was significantly higher than the retentive force needed for the 1.0 mm thick clasps. Nevertheless, undercut showed a significant effect on clasps retention with the 0.50 mm undercut provided the higher retention.

The retentive force required for removal of the 1.5 mm thick resin clasps was significantly lower ($P \leq 0.001$) than that required for removal of the CoCr clasps with 0.25 mm and 0.50 mm undercuts (Table 4).

All the clasps exhibited an increase in retentive forces during the first period of cycling followed by continuous decrease till the end of the cycling but it was still significantly not different compared to the initial retentive force ($P = 0.970$).

4. Discussion

Based on the data obtained in this investigation, the CoCr clasps showed significantly higher retention force as thermoplastic resin claps. Therefore, the null hypothesis that there would be no difference in the retentive force between resin clasps and cast CoCr alloy clasps was rejected.

The retentive force is dictated by tooth shape and by clasp design. Tooth shape influences retention by determining the depth of undercut available for clasping [26]. This study was designed to compare the retentive forces of clasps in two different amounts of undercuts. The 0.25 mm undercut was chosen because it represents the undercut commonly used for CoCr clasps, while the 0.50 mm undercut was selected to simulate the cases where clasps should be placed closer to the gingival margin, where undercut tends to be deeper, thereby producing a more esthetic result.

If a clasp is too flexible, it will provide less retention for PRDP. The flexibility of a clasp is dependent on its section, length, thickness and material [26]. In the present study two thicknesses (1.0 mm and 1.5 mm) have been selected to make the thermoplastic resin clasps.

Turner et al. examined the flexural properties of POM to determine the appropriate designs for the PRDP clasp. They suggested that a suitable POM clasp must be approximately 5 mm shorter with a larger cross-sectional diameter (approximately 1.4 mm) in order to have the stiffness similar to a cast CoCr clasp 15 mm long and 1 mm in diameter [8]. Also, Fitton et al. stated that the POM clasps must have greater cross-section area than metal claps to provide adequate retention [7]. The results of the present study verify these findings,

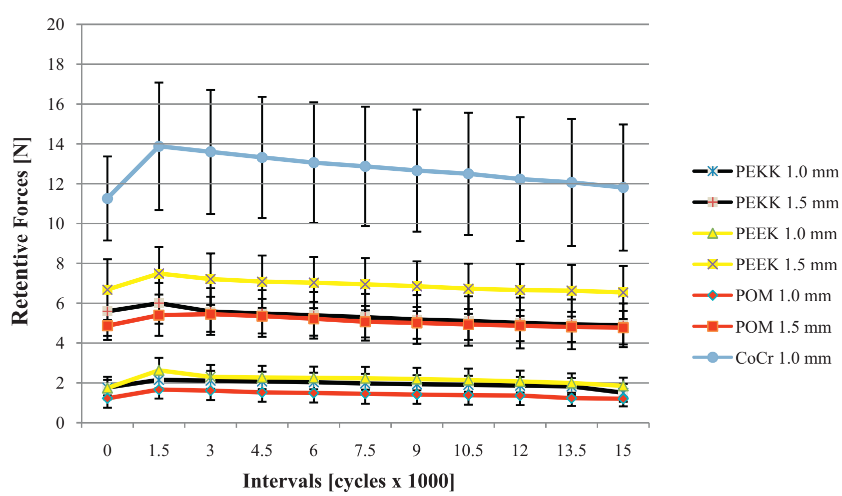

Fig. 3 – Change in forces required to remove clasps with 0.25 mm undercut.

Table 4 – Pairwise comparison of the initial retentive values (N) of Co–Cr clasps and 1.5 mm thick resin clasps.

	0.25 mm undercut		0.50 mm undercut	
	Mean (SD)	P	Mean (SD)	P
CoCr 1.0 mm	11.3 (2.1)	≤0.001	16.3 (3.8)	≤0.001
POM 1.5 mm	4.9 (0.7)		6.6 (1.1)	
CoCr 1.0 mm	11.3 (2.1)	.003	16.3 (3.8)	.001
PEEK 1.5 mm	6.7 (1.5)		8.6 (1.2)	
CoCr 1.0 mm	11.3 (2.1)	≤0.001	16.3 (3.8)	.002
PEKK 1.5 mm	5.6 (1.2)		9.1 (1.7)	

the greatest retentive force for POM clasps was found in the 1.5 mm thick clasps designed to engage the 0.50 mm undercut, the same was for PEKK and PEEK. Thermoplastic resin clasps should be thicker than metal clasps and engage a deeper undercut to gain clinically acceptable retention. This is due to the relatively low rigidity of the thermoplastic resin (elastic modulus; 2.4 GPa for POM and 4.0 GPa for PEEK and PEKK as compared to 240 GPa for CoCr alloy) [8,10].

It could be claimed that the two bulkier designs which used to make the thermoplastic clasps could prevent the self-cleaning functions and cause more plaque accumulation. However, several studies showed that if plaque control is established and a regular recall system with control, re-instruction and re-motivation is provided, removable partial dentures might not cause damage to the periodontium [27,28]. Shimura et al. found that the plaque formation on the buccal surface is not dependent on the type or placement of clasps, and suggested to prepare the guide plane as close to the gingival margin as possible to reduce the plaque accumulation on the distoproximal surface [29]. However, clinical studies are recommended to evaluate the effect of resin clasps on the plaque accumulation on the abutment teeth.

The results of the present study showed that resin clasps of both dimensions had significantly lower retentive force than CoCr clasps. Sato et al. suggested that a retentive force of 5 N is required for adequate function of PRDPs [18]. Frank and Nicholls showed that 3–7.5 N represents an acceptable amount of retention for a bilateral distal-extension PRDP [23]. In the current study, the mean retentive force for the 1.0 mm thick thermoplastic resin clasps at the end of the cycling test ranged from 1.7 N to 3.7 N, and for the 1.5 mm thick clasps from 5.4 N to 10.8 N. These results reveal that thermoplastic resins could be used in the fabrication of clasps for PRDPs, as they provide adequate retention for PRDP even after 10 years of stimulated use.

Previous studies on the fatigue resistance of CoCr clasps have indicated a loss of retention because of permanent deformation of the metal [22,24]. The results of this study showed no significant difference between the initial and the final retention. This can be explained by the method which is used to carry out the test. In the present study, the simulating test and the measurement of retentive forces have been performed using the same machine; the clasps have been fixed in the upper part of the testing machine using auto-polymerizing acrylic resin. These two procedures may reduce or eliminate all possibilities of torquing and ensured a straight path during cycling, and, thus, may have influenced the experimental outcome positively. Any excess torquing may affect the outcome of clasps negatively [20]. The increase of retention force observed in the first period of simulating could be explained by the wear between the crown and the inner surface of the clasp, which might have induced an increase in roughness of these two components during the first period of cycling, after that, the increased wear, caused a decrease in retention.

Limitations of this study include that the test was performed in a rigid system. The results under clinical conditions may not be the same due to the presence of periodontal ligament which allows physiological mobility of natural teeth. In the mouth, there are usually different insertion and removal paths, since obtaining truly effective guide planes is

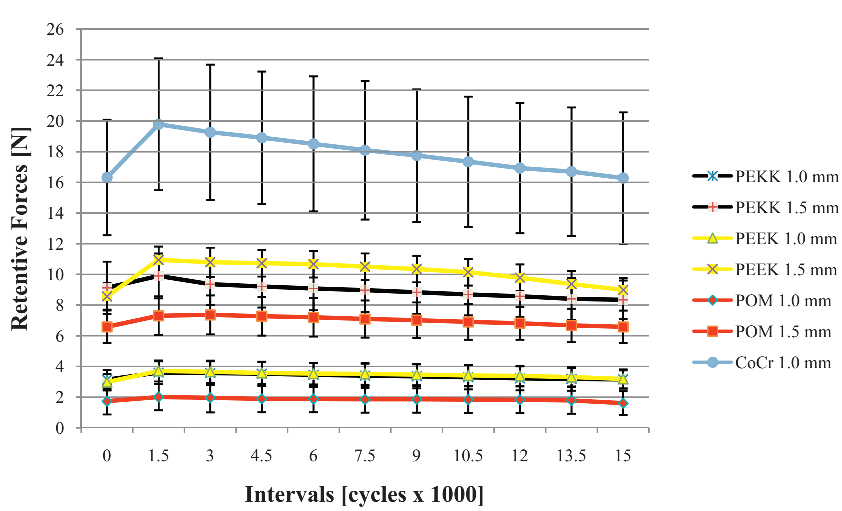

Fig. 4 – Change in forces required to remove clasps with 0.50 mm undercut.

conditioned by anatomical aspects. Additionally, patients can change the path used to move the denture at each insertion and/or removal cycle, producing greater loads on the tooth, thus leading to permanent clasp defects in a short period of time. These factors may have increased the retentive force values for the test compared to actual clinical usage. Therefore, further studies are needed, in conditions closer to clinical situations.

5. Conclusion

Within the limitation of this study, it was found that the thermoplastic resin clasps maintained retention over 15,000 joining and separating cycles with significantly lower retention than CoCr clasps. However, the retention of adequately designed resin clasps might be sufficient for clinical use.

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