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**RETENTIVE FORCES AND FATIGUE RESISTANCE OF
THERMOPLASTIC RESIN CLASPS**

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List of abbreviations

List of abbreviations:

CoCr: Cobalt chromium

PAEK: Polyaryletherketone

PEEK: Polyetheretherketon

PEKK: Polyetherketonketon

PFDP: Partial fixed dental prosthesis

PMMA: Polymethylmethacrylate

POM: Polyoxymethylene

PRDP: Partial removable dental prosthesis

1. Introduction

1.1. Need for partial removable dental prostheses (PRDPs)

There is a steady trend towards an increase in the global population that is over 65 years old [34]. Over the past 50 years, tremendous emphasis has been placed on preventive dentistry and improving attitudes about the value of retaining natural teeth. The results of these efforts have been a significant improvement in oral health, a steady decline in the prevalence of natural tooth loss, and a reduction in the percentage of edentulous people [31, 45]. Consequently, the need for restoration of partially edentulous conditions will also be increasing [15].

For the elderly, PRDPs are one of the main types of restoration for missing teeth [69]. The replacement of missing teeth with a PRDP is linked to socio-economic status, demographics, education attainment levels and income. Patients with lower educational and socio-economic levels, or those living in rural areas, are more likely to choose an PRDP over a fixed modality [69].

1.2. Advantages of a PRDP

1. A PRDP can replace lost supporting tissues in addition to missing teeth. Normal contour, appearance, and facial support may be restored with the acrylic resin denture base material where bone and alveolar tissue have been lost.
2. A PRDP can use soft tissue areas of the mouth for support in addition to using the teeth, so a PRDP may function successfully when the teeth alone cannot support a partial fixed dental prosthesis (PFDP).
3. A PRDP may help the patient maintain a more acceptable level of oral hygiene. Use of a PRDP enables the patient to clean both the prosthesis and the remaining natural teeth, since the prosthesis can be removed.
4. A PRDP may be designed to splint and stabilize weakened abutment teeth and prevent the loosening, drifting, or extrusion of retained teeth. The cost of cast restorations and

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the problem of unhygienic soldered splints may sometimes be avoided when a PRDP is used.

5. A PRDP may be designed to distribute the forces of mastication on to many support areas and to multiple abutment teeth to prevent overloading only two or three teeth [31].

1.3. Retention of a PRDP

Retention is the ability of a PRDP to resist dislodging forces during function and can be achieved by [12]:

1. Using mechanical means such as clasps which engage undercuts on the tooth surface.
2. Harnessing the patient's muscular control acting through the polished surface of the denture.
3. Using the inherent physical forces which arise from coverage of the mucosa by the denture.

1.4. Mechanical retention and clasps function

The clasp assembly is that part of a PRDP that acts as a direct retainer to prevent dislodgement by encompassing and contacting an abutment tooth. It is composed of a rest, a retentive arm, proximal plate, and bracing components (Fig. 1) [31].

There are six factors that are required of a clasp assembly [31]:

1. Retention: Provides resistance to vertical dislodgement.
2. Stability: Provides resistance to horizontal forces.
3. Support: Provides resistance to vertical seating.
4. Reciprocation: Provides resistance to horizontal forces exerted on a tooth by an active retentive clasp.

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1. Encirclement: Engages the tooth greater than 180° to prevent horizontal tooth movement from within the confines of a clasp assembly.
2. Passivity: Puts no active force on a tooth when a clasp is in place.

Whatever type of clasp is used a denture will be retained successfully only as long as the force required to flex the clasps over the maximum bulbosities of the teeth is greater than the force which is attempting to dislodge the denture [12].

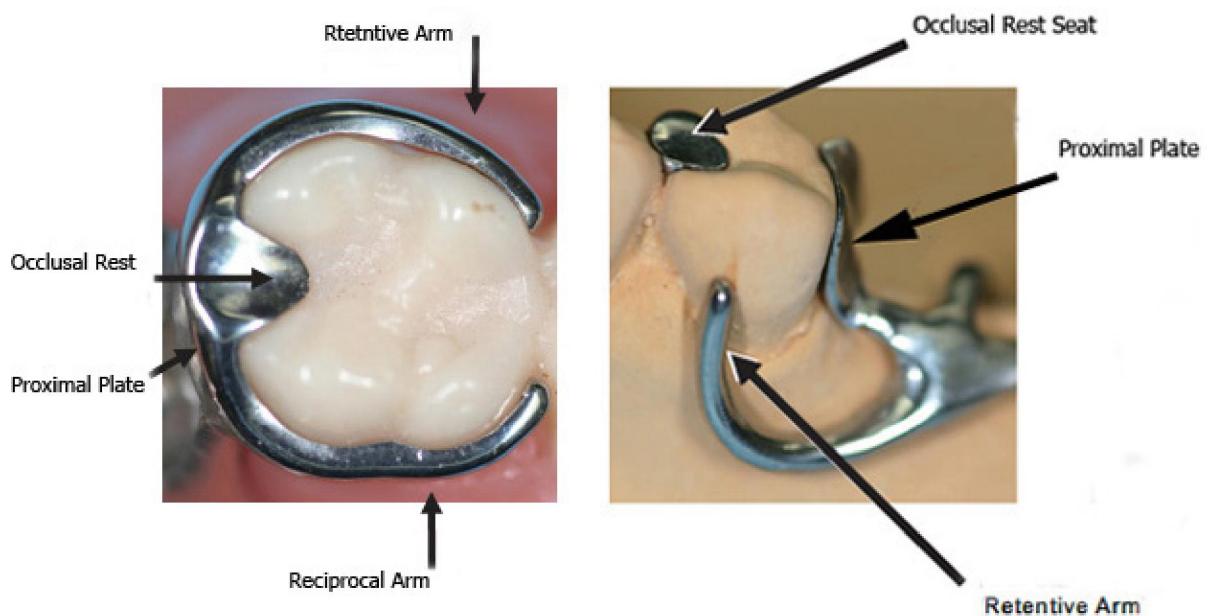


Fig.1. Circumferential clasp (left) and bar clasp (right) [31].

The retentive force is dictated by the condition of the abutment (shape, friction, and degree of undercut) and by the stiffness of the clasp arm (shapes and Young's modulus) [12, 51-52].

The flexibility of a clasp is dependent on its design [12]:

- § Section: A round section clasp will flex equally in all directions, whereas a half round clasp will flex more readily in the horizontal than in the vertical plane.
- § Length: The longer the clasp arm the more flexible it is. Thus an occlusally approaching clasp on a molar tooth will be more flexible than one on a premolar.

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- § Thickness: Thickness has a profound effect on flexibility. If the thickness is reduced by half the flexibility is increased by a factor of eight.
- § Curvature: A clasp which is curved in two planes can exhibit the so-called 'bucket handle' effect in which torsional movement of the clasp increases flexibility of the clasp arm.
- § Alloy: Although all cast alloys used in PRDP construction possess flexibility, their flexibility is proportionate to their bulk [9].

The most common metal alloy used for this purpose is a cobalt-chromium alloy, but other alloys such as gold and titanium alloys can also be used [35, 49, 63, 65]. Round wrought wires flex in all directions and have been recommended for use as retentive clasp arms in all types of PRDPs, especially where periodontal support has been compromised, or the use of cast clasps has been deemed unsuitable. However, wrought wires have several potential disadvantages related to the failure as a result of poor adaptation, loss of adaption after a period of use and susceptibility [21, 64].

1.5. Esthetics and PRDPs

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 [14]. 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.

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Many methods have been used to overcome the esthetic problem such as:

1.5.1. Camouflaging of PRDP clasps

Etching the clasp arm and coating it with a layer of tooth-color resin, has been reported in the literature [44]. The difficulty with the use of acrylic resins or resin composite to veneer to PRDP metals lies in the differences between their abilities to flex and their coefficients of thermal expansion. Non-noble metals possess strength and resist significant flexure. However, resins are subjected to greater deformation from physical and thermal conditions. The resin composite matrix also tends to be brittle beyond its elastic limit. As a result, the abilities of the metals and resins to deform plastically are incompatible. Other concerns include the effect of the intraoral forces of mastication, the adjustability of veneered clasps, and the additional bulk of the clasp created by the addition of the veneering material. Excessive shortening and thinning of the clasp should be avoided to ensure rigidity and minimize the breakage potential of the clasp [56].

1.5.2. Rotational path PRDPs

The rotational path PRDP is a relatively uncomplicated method that eliminates the use of esthetically objectionable clasping in the anterior region of the mouth [3-4, 8, 10, 19, 24, 26, 28-30, 38, 50, 57, 66-67]. It uses an anterior rigid portion of the framework and a conventional flexible posterior retentive clasp as the retentive components. The main advantage of this design is the minimal use of clasps. The esthetic result is enhanced, and the tendency toward plaque accumulation is reduced. However, both the clinical and laboratory procedures required for the rotational path PRDP are technique sensitive.

1.5.3. Lingual retention design

By eliminating the bracing arm and having its functions taken by paralleled guide planes and precise, positive rests, the retentive element, a lingual circumferential wire clasp arm, will provide the same amount of retentive force as if it were placed on the buccal surface and will not be visible [7, 10, 47].

1.5.4. Tooth-colored clasps

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 [1, 20, 61]. However, little information on the long-term performance of such clasps regarding retention is available in the literature.

1.6. Thermoplastic resins

1.6.1. Polyoxymethylene (POM)

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 [20] (Fig. 2). POM has a high degree of crystallinity and is known as one of the strongest and stiffest thermoplastic materials. In addition, it is a chemically very stable material, resistant to many solvents, disinfectants and to humidity, These properties, combined with the approved tissue compatibility, make POM a desirable material for medical application [16].

For more than two decades, POM has been used in dentistry all over the world as a substitute for acrylic resins and metals in many prosthetic applications. The most widely used appliances were the esthetic clasps of partial removable dental prostheses [1, 10, 58, 61], cast posts and cores [11, 42] and brackets [18].

1.6.2. Polyetheretherketon (PEEK) and Polyetherketonketon (PEKK)

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 [17, 36] (Fig. 2).

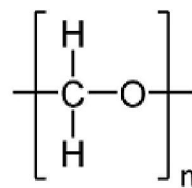
The chemical structure of polyaromatic ketones confers stability at high temperatures (exceeding 300 °C), resistance to chemical and radiation damage, compatibility with many

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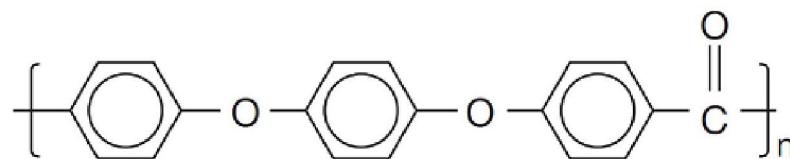
reinforcing agents (such as glass and carbon fibers), and greater strength (on a per mass basis) than many metals, making it highly attractive in industrial applications, such as aircraft and turbine blades [36].

Although neat (unfilled) polyaromatic polymers can exhibit an elastic modulus ranging from 3 to 4 GPa, the modulus can be tailored to closely match cortical bone (18 GPa) or titanium alloy (110 GPa) by preparing carbon-fiber-reinforced (CFR) composites with varying fiber length and orientation [36].

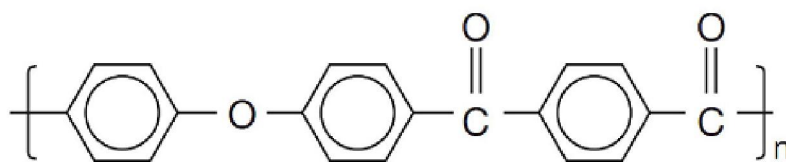
In medicine PAEK has been demonstrated to be excellent substitute for titanium in orthopedic applications [36, 60], and it has been used in dentistry as provisional implant abutment [59].



Poly – Oxy – Methylene (*POM*)



Poly – Ether – Ether – Keton (*PEEK*)



Poly – Ether – Keton – Keton (*PEKK*)

Fig. 2. Chemical structure of POM, PEEK and PEKK.

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1.7. Physical properties of clasp materials

Various metallic materials have been used to fabricate the clasps of PRDPs and the physical properties of these materials have been examined [6, 22, 25, 39-41, 49, 51-53, 63]. The most common alloys used for clasps are cobalt-chromium (CoCr) alloys [63].

CoCr alloy has a value for modulus of elasticity (stiffness) indicated by the steepness of the first part of the black curve, which is twice that of gold alloy (Fig. 3). Thus, under identical conditions the force required to deflect the cobalt chromium clasp over the bulbosity of the tooth will be twice that of a gold clasp [12].

Of particular importance is the proportional limit of the alloy indicated by the solid circles on the curves. If a clasp is stressed beyond the proportional limit it will be distorted permanently. Hard gold and cobalt chromium have similar proportional limits. Hardened stainless steel wire (blue curve) has a much higher value [12].

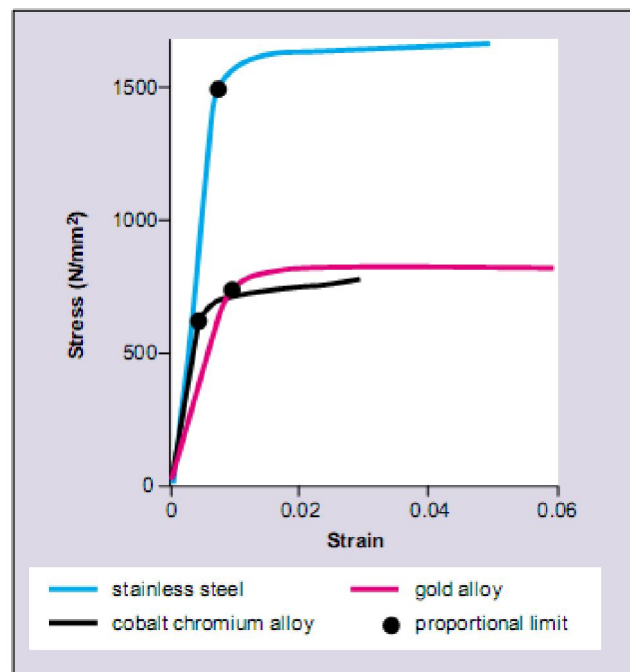


Fig. 3. Stress strain curve CoCr alloy, gold alloy and stainless steel [12].

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1.7.1. Fatigue test

Fatigue is the loss of strength and other important properties as a result of stressing a material over a quite long period of time. Fatigue is very important, as it is the single largest cause of failures in metals, estimated as about 90% of metallic failures; polymers and ceramics are also susceptible to this type of failure.

Clasps undergo permanent deformation to cause fatigue fracture under repeated flexures during denture insertion and removal, and masticatory actions [9, 32]. Permanent deformation and fatigue fracture are caused by the stress created in the clasp [23, 62]. The stress distribution may depend on the elastic modulus of the alloy, dimensions and curvature of the clasp [54, 68], and amount and direction of deflection in relation to the abutment undercut [51].

There have been studies that investigated the retention properties of CoCr alloys using repeated insertion/removal tests. Rodriguez et al. indicated an increase in retentive force during the simulation test [49], while retention decrease was reported by Bridgeman et al. [6] and Kim et al. [33].

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 [35]. Previous studies indicated that PRDP clasps made of more elastic materials like titanium and gold demonstrated a higher resistance to retention loss [33, 35].

Mahmoud et al. [40] investigated gold alloy and Ti6Al7Nb, which were subjected to cyclic deflection of pre-set values of 0.25, 0.50, and 0.75 mm for 106 cycles. It was concluded that the gold alloy clasps exhibited significantly longer fatigue lives, while the Ti6Al7Nb clasps showed significantly greater resistance to permanent deformation under cyclic deflection [40].

The fatigue resistances of experimentally prepared NiTi (50.8%Ni-49.2%Ti) cast clasps as well as CpTi, CoCr alloy, and AuAgPdCu alloy clasps were evaluated in a simulated clinical situation [35]. The change in force required to remove the NiTi clasps was recorded under a repeated placement–removal test on steel model abutment teeth. The tips of the clasps were located in a 0.25 and 0.5 mm undercut area of the abutments. It was found that (1) no significant change in the retentive force was found in NiTi clasps during 1010 repeated

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cycles, but (2) the other three types of clasps revealed a significant decrease in the force required for removal during the test [35].

1.7.2. Thermoplastic resins and PRDPs

Polyoxymethylene (POM) was used for the construction of retentive and supportive components of partial removable dental prostheses (PRDPs) to improve aesthetics. Since the introduction of POMs, there has been a continued interest in its use for PRDP applications [1, 10, 20, 37, 48, 61]. Chu considered it a simple and effective means of improving PRDP aesthetics [10]. Polyacetal resin clasps (POM clasps) were also suggested for use instead of the metal clasps during radiation therapy to prevent backscatter from radiation [58].

The design, retentive force, colour stability, water sorption and solubility of POM clasps have been investigated. Arda and Arikan performed an in vitro study to compare the retentive force and deformation of POM and cobalt-chromium clasps [1]. They found that the mean dislodgement force for POM clasps was significantly lower than that for CoCr clasps. However, flexibility of POM clasps would allow for the retentive clasp arms of PRDPs to be placed in deeper undercuts on abutments. Further, the flexibility and long-term retentive resiliency of the clasps suggest that POM clasps may be suitable for PRDPs when aesthetics or periodontal health is of primary concern.

Turner et al. examined the flexural properties of POM to determine the appropriate design for the POM clasps [61]. They also evaluated the effectiveness of various POM polishing procedures. They suggested that a suitable POM clasp must be approximately 5 mm shorter than CoCr clasps 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.

Arikan et al. compared water sorption and water solubility of pink and white acetal resin to a heatpolymerized polymethyl methacrylate resin (PMMA) [2]. The result showed that pink acetal resin had significantly lower water sorption than PMMA and white acetal resin. PMMA showed higher solubility than pink and white POM.

Ozkan et al. also did a study to access the colour stability of polyacetal resin subjected to thermocycling and showed it has clinically acceptable discolouration values [46].

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However, to the best knowledge of the author there are no studies evaluating the use of PEEK and PEKK as clasp materials. Due to the low modulus of elasticity (2-4 GPa) [36, 61], thermoplastic resin has superior flexibility compared to the conventional CoCr alloys. The increased flexibility of a resin direct retainer permits its placement more cervically without deformation or producing more stress on the abutment teeth which is of importance for improved esthetics and predictable long-term use of a PRDP [54].

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1.8 Purpose of the study

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.

Materials and methods

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.

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

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

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with a surveyor blade to standardize the path of insertion. The waxed two 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 in polyether impression material (Impregum Penta H and L) with custom impression trays.

2.2.1. CoCr Clasps

The impressions were poured with die-investment material (Obtinvest, DeguDent, Hanau, Germany) to make refractory casts for the CoCr clasps.

Preformed half-round tapered clasp patterns (1.0 mm thick) with occlusal rests, and retentive and reciprocal arms (Wachsprofile, Bego) (Fig. 4) were adapted along the ledges formed with block-out material prior to making definitive 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 (Obtinvest, DeguDent) according to the manufacturer's instructions and cast in CoCr alloy. Finally the clasps were trimmed, airborne-particle abraded with 50 μ m alumina at 0.25 MPa pressure. To ensure uniformity of clasps, no polishing was performed.

Materials and methods

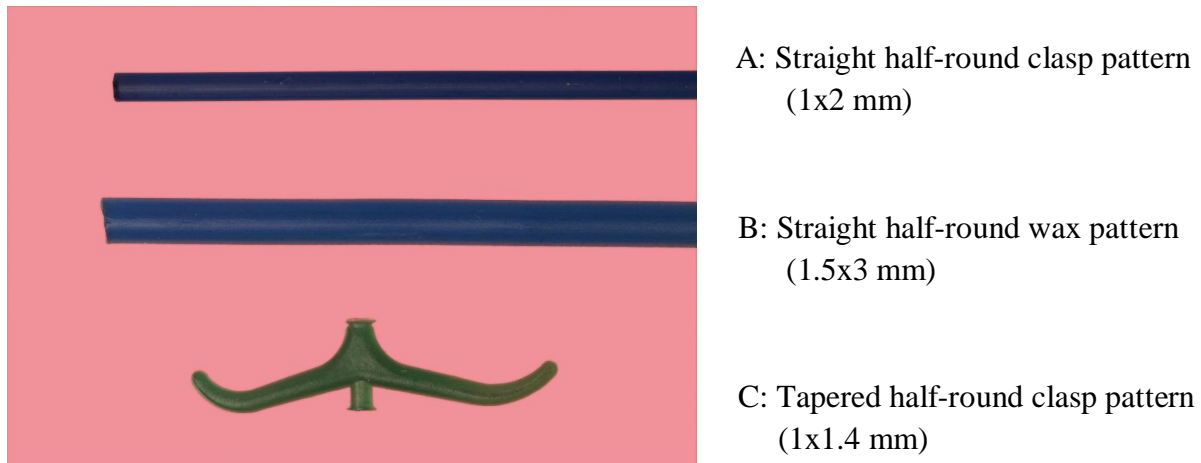


Fig. 4. Wax patterns used to make the clasps.

2.2.2. POM clasps

The impressions were poured with Type IV dental stone (Marble Stone; Dental Srl, San Marino, Italy) to make refractory casts.

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) (Fig. 4) were used. The previously described wax sprue was connected to the residual ridge base parallel to the path of insertion using a surveyor.

First, the assembly (stone model and clasp pattern) was placed at a distance of approximately 2.5 cm from the injection opening of the special flask (Muffle-Type 100; Pressing Dental Srl) with Type IV dental stone (GC Fujirock EP, GC). When the flask was set-up, it was reopened and the wax is removed with boiling water. The flask is closed again and placed into an oven at 100°C for 30 minutes.

POM cylinders were placed into the injection sleeve, teflon plunger was placed into the sleeve on top of the resin material and pushed down, and then the sleeve was placed in the injection machine (J-100; Pressing Dental Srl) (Fig. 5). The parameters of the injection machine were set as follows: pre-injection time with the material maintained at 220°C (melting temperature) for 20 minutes, post-injection time with the temperature maintained at the desired level of

Materials and methods

220°C for 5 minutes, injection cooling for 60 minutes, and injection pressure of 4 bar. At the end of the process, the flask was removed from the initial position, and the clasp was deflasked.

Injection settings of POM*:

Pre-heating temperature/time	100°C /30 min
Melting temperature	220°C
Pre-injection time	20 min
Injection pressure	4 bar
Post-injection time	5 min
Cooling time	60 min
Injection device	J-100; Pressing Dental Srl, San Marino, Italy

*according to the manufacturer



Fig. 5. Injection machine (J-100).

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2.2.3. PEEK clasps

The impressions were with poured Type IV dental stone (Expando-Rock; Bredent, Senden, Germany) to make refractory casts.

For fabrication of the 1.0 mm and 1.5 mm thick thermoplastic resin clasps straight semicircular clasp patterns (Wax patterns, Omnident) (Fig. 4) were used. The previously described wax sprue was connected to the residual ridge base parallel to the path of insertion using a surveyor.

First, the assembly (stone model and clasp pattern) was placed at a distance of approximately 2.5 cm from the injection opening of the special flask (Thermopress flask N; Bredent) with Type IV dental stone (GC Fujirock EP, GC). When the flask was set-up, it was reopened and the wax is removed with boiling water. The flask is closed again and placed into an oven at 200°C for 20 minutes.

The injection sleeve filled with PEEK was placed in the injection machine (Thermopress 400 injection moulding system; Bredent) (Fig. 6). The parameters of the injection machine were set as follows: pre-injection time with the material maintained at 380°C (melting temperature) for 25 minutes, post-injection time with the temperature maintained at the desired level of 220°C for 2 minutes, injection cooling for 60 minutes, and injection pressure of 4 bar. At the end of the process, the flask was removed from the initial position, and the clasp was deflasked.

Injection settings of PEEK*:

Pre-heating temperature/time	200°C /20 min
Melting temperature	380°C
Pre-injection time	25 min
Injection pressure	4 bar
Post-injection time	2 min
Cooling time	60 min
Injection device	Thermopress 400 injection moulding system; Bredent

*according to the manufacturer

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2.2.4 PEKK clasps

The impressions were poured with die-investment material (Obtinvest, DeguDent, Hanau, Germany) to make refractory casts.

For fabrication of the 1.0 mm and 1.5 mm thick thermoplastic resin clasps straight semicircular clasp patterns (Wax patterns, Omnident) (Fig. 4) were used. The previously described wax sprue was connected to the residual ridge base parallel to the path of insertion using a surveyor.

Each assembly (die and pattern) was invested (Obtinvest, DeguDent) according to the manufacturer's instructions using a special muffle (thermopress 400 Muffel-System, Bredent).

The injection procedure was performed using the injection machine (Thermopress 400 injection moulding system; Bredent) (Fig. 6). The parameters of the injection machine were set as follows: pre-injection time with the material maintained at 325°C (melting temperature) for 20 minutes, post-injection time with the temperature maintained at the desired level of 325°C for 1 minutes, injection cooling for 60 minutes, and injection pressure of 7 bar. At the end of the process, the flask was removed from the initial position, and the clasp was deflasked.

Injection settings of PEKK*:

Pre-heating temperature/time	150°C /30 min
Melting temperature	325°C
Pre-injection time	20 min
Injection pressure	7 bar
Post-injection time	1 min
Cooling time	60 min
Injection device	Thermopress 400 injection moulding system; Bredent

*according to the manufacturer

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 (Fig. 7).



Fig. 6. Injection machine (Thermopress 400).

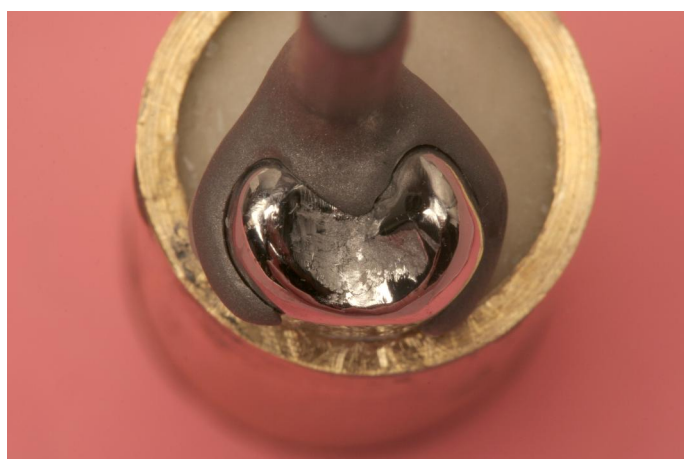
Materials and methods



A: Thermoplastic resin clasp 1 mm



B: Thermoplastic resin clasp 1.5 mm



C: CoCr clasp 1 mm

Fig. 7. Clasps on their abutment models.

Materials and methods

2.3 Test conditions

To perform the retention test, a masticatory simulator (Willytec, Munich, Germany) (Fig. 8) was used. The machine allowed 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) (Fig. 9). The test conditions were maintained at room temperature (20 ± 2 °C) and wet condition (deionised water). To analyze the data obtained during the simulation test, intervals every 1,500 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 removals and insertions of the PRDP 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 four-way and two-way analyses of variance (ANOVA). Significance level was set at 5% ($\alpha = 0.05$).

Materials and methods

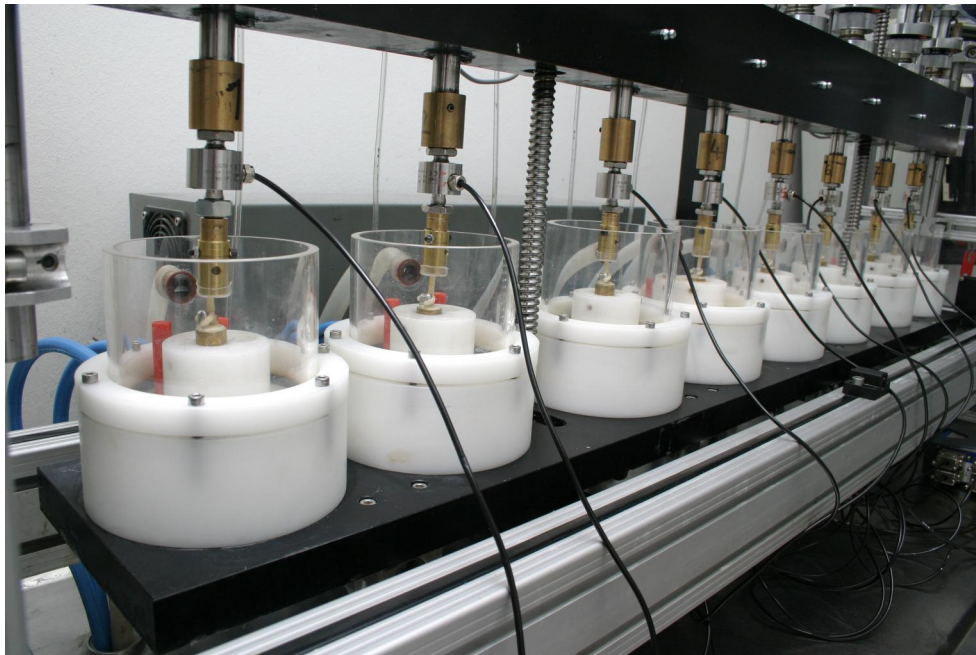


Fig. 8. Computer controlled masticatory simulator with mounted specimen in eight trial cells.

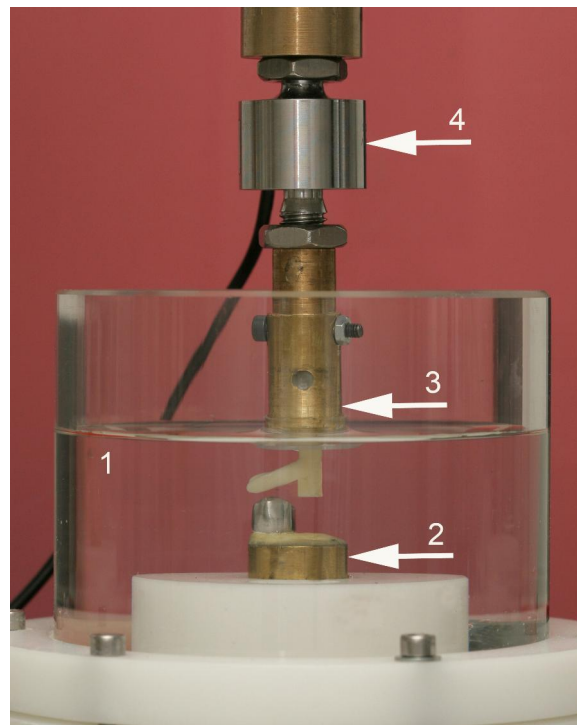


Fig. 9. Test set-up in a loading chamber of masticatory simulator. (1) loading chambers filled with water, (2) holder with abutment crown, (3) holder with the clasp, and (4) force transducer.

Results

3. Results

Tables 2 and 3 show the mean retention forces for all subgroups at all test intervals. 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 the 1.5 mm thick resin clasps. 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.

After 15,000 insertion-removal cycles the mean retentive force ranged from 1.2 to 3.2 N for the 1.0 mm thick resin clasps and from 4.8 to 9.0 N for the 1.5 mm thick resin clasps. For CoCr clasps it ranged from 11.8 to 16.3 N. The highest final 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.

Figures 10 and 11 show the changes in retentive force required to remove clasps from the 0.25 mm and 0.50 mm undercuts.

Results

Table 2. Mean retention forces (N) for all subgroups with 0.25 mm undercuts at the different time intervals.

Intervals	CoCr	PEEK	PEEK	PEKK	PEKK	POM	POM
	1.0 mm	1.0 mm	1.5 mm	1.0 mm	1.5 mm	1.0 mm	1.5 mm
0 cycle	11.3	1.7	6.7	1.8	5.6	1.2	4.9
1500 cycles	13.9	2.6	7.5	2.2	6.0	1.7	5.4
3000 cycles	13.6	2.3	7.2	2.1	5.6	1.6	5.5
4500 cycles	13.3	2.3	7.1	2.1	5.5	1.5	5.4
6000 cycles	13.1	2.3	7.0	2.0	5.4	1.5	5.2
7500 cycles	12.9	2.2	7.0	2.0	5.3	1.5	5.1
9000 cycles	12.7	2.2	6.9	1.9	5.2	1.4	5.0
10500 cycles	12.5	2.1	6.7	1.9	5.1	1.4	4.9
12000 cycles	12.2	2.1	6.7	1.9	5.0	1.4	4.9
13500 cycles	12.1	2.0	6.6	1.8	4.9	1.2	4.8
15000 cycles	11.8	1.9	6.5	1.5	4.9	1.2	4.8

Table 3. Mean retention forces (N) for all subgroups with 0.5 mm undercuts at the different time intervals.

Intervals	CoCr 1.0	PEEK	PEEK 1.5	PEKK	PEKK	POM	POM
	mm	1.0 mm	mm	1.0 mm	1.5 mm	1.0 mm	1.5 mm
0 cycle	16.3	3.0	8.6	3.1	9.1	1.7	6.6
1500 cycles	19.8	3.7	11.0	3.6	9.9	2.0	7.3
3000 cycles	19.3	3.7	10.8	3.6	9.4	2.0	7.4
4500 cycles	18.9	3.6	10.7	3.5	9.2	1.9	7.3
6000 cycles	18.5	3.5	10.7	3.5	9.1	1.9	7.2
7500 cycles	18.1	3.5	10.5	3.4	9.0	1.9	7.1
9000 cycles	17.8	3.5	10.4	3.4	8.8	1.9	7.0
10500 cycles	17.4	3.4	10.1	3.3	8.7	1.8	6.9
12000 cycles	16.9	3.4	9.8	3.2	8.6	1.8	6.8
13500 cycles	16.7	3.3	9.4	3.2	8.4	1.8	6.7
15000 cycles	16.3	3.2	9.0	3.2	8.3	1.6	6.6

Results

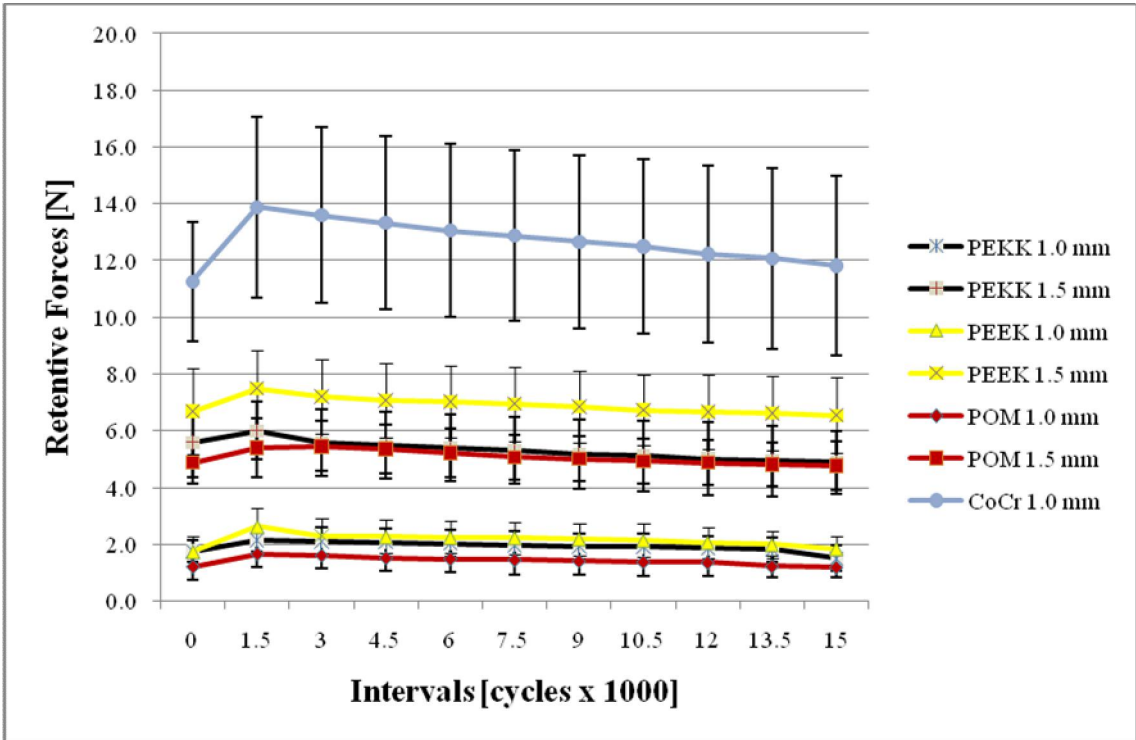


Fig. 10. Change in forces required to remove clasps in groups with 0.25 mm undercut.

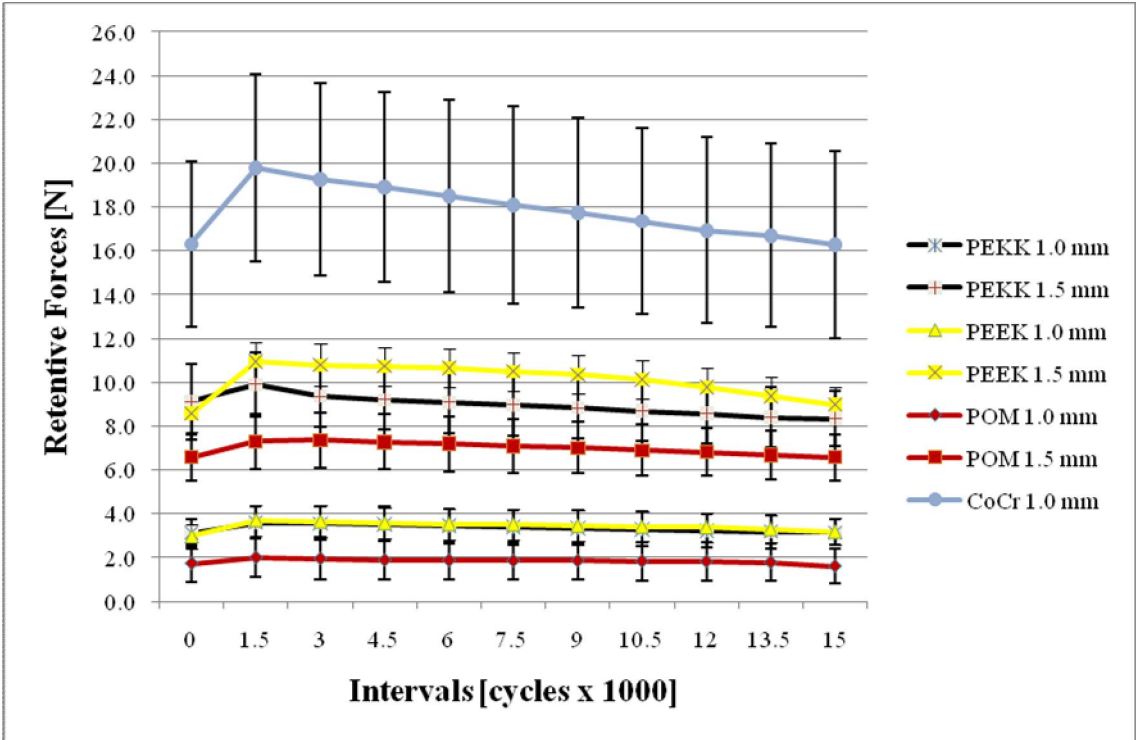


Fig. 11. Change in forces required to remove clasps in groups with 0.50 mm undercut.

Results

Results of the 4-way ANOVA for the resin clasps indicated a significant influence of the three tested factors (material, thickness, and undercut) on the mean retention force (P 0.001). PEEK exhibited the highest retention followed by PEKK and POM (P 0.001). The retentive force required to dislodge 1.5 mm thick resin clasps was significantly higher than the retentive force needed for 1.0 mm thick clasps. Also the amount of undercuts showed a significant effect on clasps retention with the 0.50 mm undercut provided the higher retention, while there was no significant influence of the cycling factor on the mean retention force (P>0.05) (Table 4). However, 2 significant interactions were found between (a) undercut and material and (b) undercut and thickness. Therefore, a 2-way ANOVA was performed separately for each undercut.

Table 4. Comparison between mean retention forces (PEEK, PEKK, POM) using 4-way ANOVA

Source	Type III sum of squares	df	Mean square	F	Sig.
Material	75.990	2	37.995	41.501	<.000
Undercut	153.189	1	153.189	167.323	<.000
Thickness	1074.940	1	1074.940	1174.120	<.000
Time	.248	1	.248	.271	.603
Material x Undercut	14.831	2	7.416	8.100	<.000
Material x Thickness	9.013	2	4.506	4.922	.078
Material x Time	2.914	2	1.457	1.591	.207
Undercut x Thickness	27.376	1	27.376	29.902	.000
Undercut x Time	.278	1	.278	.303	.583
Thickness x Time	.234	1	.234	.255	.614
Material x Undercut x Thickness	2.579	2	1.290	1.409	.247
Material x Undercut x Time	.968	2	.484	.528	.591
Material x Thickness x Time	1.020	2	.510	.557	.574
Undercut x Thickness x Time	.431	1	.431	.471	.493
Material x Undercut x Thickness x Time	.534	2	.267	.292	.747
Error	153.809	168	.916		
Total	5360.590	192			

Results

The 2-way ANOVA of the both undercuts revealed a significant effect of the material and thickness on the mean retention force (Tables 5 and 6). However, comparisons of the means of the three tested resin materials POM, PEKK, and PEEK, with the Tukey multiple range test showed no significant difference between POM and PEKK at 0.25 mm undercut, while at 0.50 mm undercut, there was no significant difference between PEKK and PEEK (Tab. 7).

Table 5. Summary of 2-way ANOVA for the 0.25 mm undercut

Source	Type III sum of squares	df	Mean square	F	Sig.
Material	18.913	2	9.457	12.039	<.000
Thickness	388.621	1	388.621	494.755	<.000
Material x Thickness	6.680	2	3.340	4.252	.117
Thickness x Time	.901	1	.901	1.147	.287
Error	66.766	85	.785		
Total	1745.230	97			

Table 6. Summary of 2-way ANOVA for the 0.50 mm undercut

Source	Type III sum of squares	df	Mean square	F	Sig.
Material	70.771	2	35.386	33.357	<.000
Thickness	722.704	1	722.704	681.260	<.000
Material x Thickness	4.508	2	2.254	2.125	.126
Thickness x Time	.015	1	.015	.014	.906
Error	89.110	84	1.061		
Total	3656.320	96			

Results

Table 7. Comparison of the means of retention force with each undercut

	Undercut 0.25 mm		Undercut 0.5 mm	
POM	3.1	A	4.1	A
PEKK	3.5	A	5.9	B
PEEK	4.1	B	6.0	B

Within the same column, means with same upper case letter are not significantly different.

The retentive force required for removal of the 1.5 mm thick resin clasps was significantly lower ($P = 0.001$) than that required for removal of the CoCr clasps with 0.25 mm and 0.50 mm undercuts (Tab. 8 and 9).

Table 8. Pair-wise comparison of the initial retentive values (N) of CoCr 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)	<.001	16.3 (3.8)	<.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)	<.001	16.3 (3.8)	.002
PEKK 1.5 mm	5.6 (1.2)		9.1 (1.7)	

Table 9. Pair-wise comparison of the final retentive values (N) of CoCr 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	11.8 (3.2)	<.001	16.3 (4.3)	<.001
POM 1.5 mm	4.9 (0.8)		6.6 (1.1)	
CoCr 1.0 mm	11.8 (3.2)	.003	16.3 (4.3)	.003
PEEK 1.5 mm	6.4 (1.3)		9.3 (1.3)	
CoCr 1.0 mm	11.8 (3.2)	<.001	16.3 (4.3)	.002
PEKK 1.5 mm	4.9 (1.1)		8.5 (1.3)	

Results

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 not significantly different compared to the initial retentive forces ($P>0.05$).

SEM images

After the cycling test the abutment models of CoCr groups showed some wear at contact area with the clasp tip, while no wear was detected on the models of resin clasps. In addition, the inner surface of the clasp tip of all groups showed some amount of wear (Figures 12 and 13).

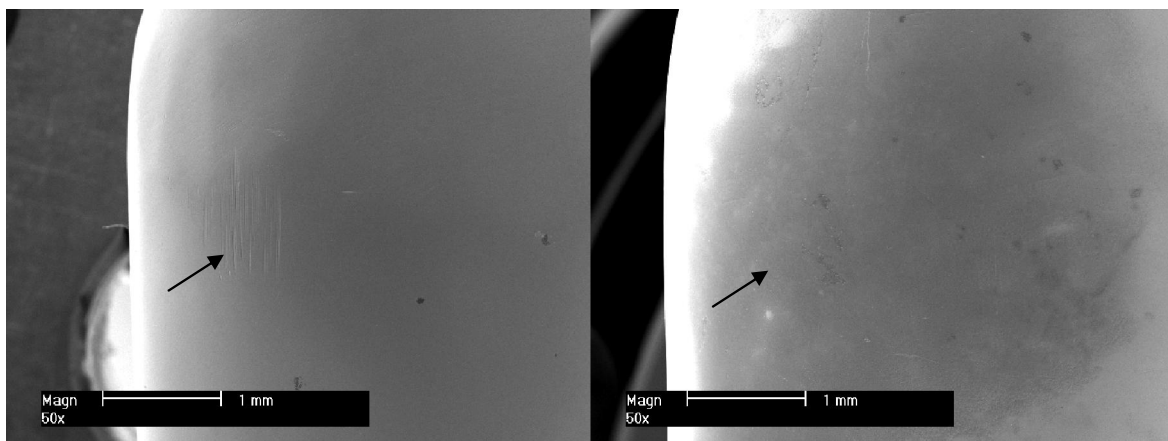


Fig. 12. SEM image of model surface at the contact area with the clasp tip (left: with CoCr clasp, right: with resin clasp). Arrows indicate some wear with CoCr clasps while no wear shown with resin clasps.

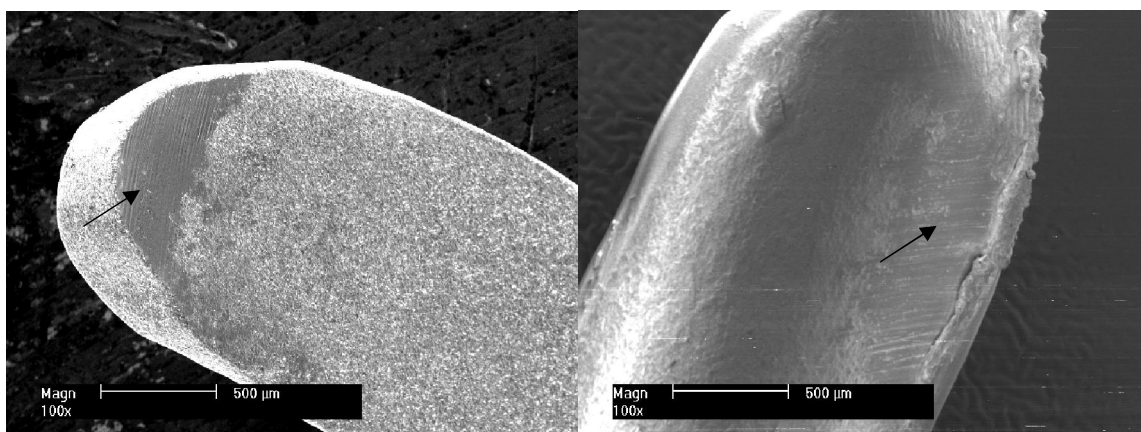


Fig. 13. SEM image of the inner surface of the clasp (left: CoCr clasp, right: resin clasp). Arrows indicate facets of wear.

Discussion

4. Discussion

4.1. Materials

Materials for clasps and frameworks of partial removable dental prostheses (PRDPs) need to have enough flexibility for the clasps and rigidity for other framework components. Therefore, CoCr is the most popular alloy for the frameworks of PRDPs. The biggest disadvantage of CoCr clasps is their poor esthetic appearance. Tooth colored clasps made of thermoplastic resins have been developed to overcome the esthetic problems. In this study CoCr alloy served as the control group while three types of thermoplastic resins (POM, PEEK, PEKK) served as test groups.

4.2. Methods

4.2.1. Abutments

A maxillary first premolar has been used to make the abutments used in this study for two reasons, (1) esthetically: because the first premolar represents an esthetic problem when it must be used as retainers for an PRDP, (2) functionally: because cast CoCr alloy can be too stiff for occlusally approaching clasps on premolar teeth, and as a result more stress on the abutment could be produced [13].

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 [12]. 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.

4.2.2. Circumferential clasp

Although a thorough knowledge of the principles of clasp design should lead to a logical application of those principles, it is better that some of the more common clasp designs be considered individually. The circumferential clasp (Fig. 1) will be considered first as an all-cast clasp [9].

The circumferential clasp is usually the most logical clasp to use with all tooth-supported partial dentures because of its retentive and stabilizing ability. Only when the retentive undercut may be approached better with a bar clasp arm or when esthetics will be enhanced should the latter be used (Fig. 1) [9].

Despite its disadvantages the cast circumferential clasp arm may be used effectively, and many of these disadvantages may be minimized by mouth preparation. Adequate mouth preparation will permit its point of origin to be placed far enough below the occlusal surface to avoid poor esthetics and increased tooth dimensions. Although some of the disadvantages listed imply that the bar-type clasp may be preferable, the circumferential clasp is actually superior to a bar clasp arm that is improperly used or poorly designed [9].

4.2.3. Dimensions of the clasp

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 [12]. In the present study two thicknesses (1.0 mm and 1.5 mm) have been selected to make the thermoplastic resin clasps.

4.2.4. Test 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).

Discussion

In previous similar studies [6, 27, 33], simulating test has been performed on a masticatory simulator, and clasp retention has been measured every cycling sequence using another machine (tensile testing machine). To get the clasp on the two machines every time in the exact same position is very difficult, this could produce greater load on the abutments and lead to retention loss in a short time. In the current study, simulating test and retention measurement have been made using the same machine; this procedure has eliminated any mismatch in the clasp position.

In the present study, every clasp had its own tooth abutment, and this has reduced the possibility of abutment wear, so that the retentive force could be measured more accurately. While in previous studies [6, 33, 49], clasp retentive forces were measured and cyclic fatigue tests were performed on a single abutment tooth.

4.3. Results

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

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[61]. Also, Fitton et al. stated that the POM clasps must have greater cross-section area than metal clasps to provide adequate retention [20]. The results of the present study verify these findings, 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; 2.36 GPa for POM and 4.0 GPa for PEEK and PEKK as compared to 240 GPa for CoCr alloy) [36, 61].

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,

Discussion

several studies showed that if plaque control is established and a regular recall system with control, re-instruction and re-motivation is provided, PRDPs might not cause damage to the periodontium [5, 43]. 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 [55]. 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 [52]. Frank et al. showed that 3 to 7.5 N represents an acceptable amount of retention for a bilateral distal-extension PRDP [22]. 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 simulated usage.

Previous studies on the fatigue resistance of CoCr clasps have indicated a loss of retention because of permanent deformation of the metal [25, 33]. The results of this study showed no significant difference between the initial and the final retention. This can be explained by the method which 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 [6]. 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

Discussion

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 conditioned by anatomical aspects. Additionally, patients can change the path used to move the PRDP 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.

Conclusion

5. Conclusions

Within the limitations of this study, the following conclusions were drawn:

1. The mean retentive force required to remove the 1.0 mm thick thermoplastic resin clasps was found to be significantly lower ($P = 0.001$) than those required for removal of the of 1.5 mm thick clasps with 0.25 mm and 0.50 mm undercuts.
2. The mean retentive force required to remove the 1.0 mm and 1.5 mm thick thermoplastic resin clasps was found to be significantly lower ($P = 0.001$) than those required for removal of the CoCr clasps with 0.25 mm and 0.50 mm undercuts.
3. The retentive force required for 1.0 mm- and 1.5 mm-thick thermoplastic resin clasps demonstrated no significant change over the simulating test of clinical usage.

Summary

6. Summary

Statement of problem: Thermoplastic resin clasps have been used recently in the partial removable dental prostheses construction. However, little is known about the long-term retentiveness of these clasps under clinical conditions.

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

Methods: On standardized premolar metal crowns 112 clasps were fabricated, including 16 CoCr (Wironit; 1.0 mm thick) clasps and 32 clasps (1.0 or 1.5 mm thick) from each of the following thermoplastic resins: Acetal-Dental, BioXS, PEKKtone A. 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 data obtained during the simulation test, intervals every 1,500 cycles were established. Data were statistically analyzed using 4-way and 2-way ANOVAs ($\alpha = 0.05$).

Results: Resin clasps with 1.5 mm thickness showed higher retention than clasps with 1.0 mm thickness ($P < 0.001$). Resin clasps of both dimensions had significantly lower retentive force than CoCr clasps ($P < 0.001$). Clasps with 0.25 mm undercut showed significantly less retention than clasps with 0.50 mm ($P < 0.001$). All the 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 ($P=0.970$).

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

Clinical Implications: Thermoplastic resin clasps were determined to maintain clinically adequate retention over 10 years simulated use. Clinical studies are required to prove that thermoplastic resins are alternative for PRDP fabrication.

7. Zusammenfassung

Beschreibung des Problems:

Klammern aus thermoplastischem Kunststoff werden seit neustem für die Konstruktion von Modellgussprothesen verwendet. Aber über die Retention dieser Klammern bei längerem klinischen Gebrauch ist wenig bekannt.

Ziele:

Das Ziel dieser Studie war es, den Halt von Klammern aus drei verschiedenen thermoplastischen Kunststoffen mit Klammern aus einer Kobalt-Chrom-Legierung zu vergleichen. Dafür wurde ein Einsetzungs-/Entfernungstest verwendet, der 10 Jahre klinischen Einsatz simuliert.

Methoden:

Auf genormten Prämolarkronen wurden 112 Klammern hergestellt, davon 16 aus einer Kobalt-Chrom-Legierung (Wironit, 1,0 mm dick) und je 32 Klammern (1,0 oder 1,5 mm dick) aus den folgenden thermoplastischen Kunststoffen: Acetal-Dental, BioXS und PEKKtone A. Die Proben wurden unterteilt in Gruppen mit Unterschnitten zu 0,25 mm bzw. 0,5 mm. Jede Klammer wurde auf ihrer Krone einem Einsetzungs-/Entfernungstest mit 15.000 Zyklen unterzogen. Um die Daten aus dem Simulationstest zu analysieren, wurden Intervalle von je 1.500 Zyklen festgelegt. Die statistische Analyse der Daten erfolgte unter Zuhilfenahme von vier- und zweifaktoriellen Univarianzanalysen ($\alpha = 0.05$).

Ergebnisse:

Die Kunststoff-Klammern mit einer Dicke von 1,5 mm wiesen eine höhere Retention auf als Klammern mit einer Dicke von nur 1,0 mm ($P < 0.001$). Kunststoff-Klammern beider Stärken zeigten signifikant schwächere Retention als die CoCr-Klammern ($P < 0.001$). Zudem wiesen Klammern mit 0,25 mm Unterschnitt eine signifikant schwächere Retention auf als Klammern mit 0,5 mm Unterschnitt ($P < 0.001$). Außerdem wiesen alle Klammern eine erhöhte Retention während des ersten Simulationsintervalls auf. Darauf folgte eine kontinuierliche Abnahme der Retention bis zum Ende der Simulation. Der Endwert der Retention war jedoch vom Anfangswert nicht statistisch signifikant verschieden ($P > 0,05$).

Schlussfolgerungen:

Die Klammern aus thermoplastischem Kunststoffen behielten ihre Retention über 15.000 Zyklen des Einsetzungs-/Entfernungstest bei, aber mit einer insgesamt geringeren Retention als die konventionellen CoCr-Klammern. Die Retention von entsprechend gestalteten Kunststoff-Klammern kann aber für den Einsatz am Patienten ausreichend sein.

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Appendix

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