

Retention behaviors of different attachment systems: Precious versus non-precious, precision versus semi-precision

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The aims of this study were to investigate the retention force changes of different attachment systems after 10,000 insertion-separation cycles and the difference in retention force between precious and non-precious materials of the same attachment system. Four types of attachments (Ball, Rod, M3 stud, and AP-Piccolino), produced using both precious and non-precious metal alloys, were tested ($n=6$). Data were analyzed using analysis of variance (ANOVA), Tukey's multiple comparison test, and t -test at a significance level of $p \leq 0.05$. Retention forces of all attachment types were significantly decreased after 10,000 insertion-separation cycles ($p \leq 0.05$). Rod and M3 attachment systems showed an initial increase in retention force, then an eventual decrease. At the end of the test, precious types of M3 and AP-Piccolino attachments had significantly higher retention force values than their non-precious ones ($p \leq 0.05$). Friction between non-precious attachment parts resulted in a higher retention loss than precious metal alloys.

Keywords: Attachment, Precious, Precision, Retention force

INTRODUCTION

Use of implant-supported fixed partial dentures has become a well-established and predictable treatment option for partially edentulous patients. However, because of low cost and inadequate remaining alveolar bone, traditional removable partial dentures (RPDs) remain the mainstay^{1,2}. To prevent dislodgment, RPDs can be retained by a clasp assembly or an attachment system. Compared to clasp-retained RPDs, attachment-retained RPDs yield several esthetic and functional advantages, such as improved esthetics, readjustable retention force, and a reduced incidence of secondary caries^{3,4}.

Attachment systems can be classified by their fabrication method and location. On the former aspect, there are precision or semi-precision attachments; on the latter aspect, there are intracoronal or extracoronal attachments⁴⁻⁶. Semi-precision attachments are fabricated by the direct casting of plastic, wax, metal, or refractory patterns. A prominent drawback associated with semi-precision attachments is that inaccuracies of the casting and fitting processes may compromise the fit of the completed RPDs. Precision attachments are similar to semi-precision attachments except that their components are manufactured to very tight tolerances and are held together by precise alignments. The retention of attachments is achieved through mechanical interlocking and frictional contact between the matrix and patrix^{7,8}. With semi-precision attachments, matrices and patrices are usually cast components fabricated by using prefabricated plastic patterns.

Attachment-retained dentures have garnered high patient satisfaction because of their retention

characteristics. However, they require routine maintenance and periodic repairs because they are susceptible to wear and damage, and hence loss of retention. The degree of wear depends on the design and material of the attachment. Attachments can be made of precious or non-precious metal alloys. Attachments made of high-gold-content alloys were reportedly more resistant to wear than alloys containing non-precious metals^{5,9,10}. Besides, exchangeable plastic matrices and adjustable patrices are widely used to regulate the retention force of attachments.

The retentive properties of attachments are affected by a combination of factors: design, fabrication method, and production material⁹. For example, ball, rod, and stud attachments can be fabricated using different materials and designs. Since the retention of attachments plays a critical role in the survival of attachment-retained dentures, the retention behaviors of different attachment types should be clarified. The aims of the present study were twofold: (1) to investigate and compare the retention behaviors of four different types of attachments after 10,000 insertion-separation cycles in a wear simulator; and (2) to investigate the differences in retention behavior between precious and non-precious materials of the same attachment system. The null hypothesis was that four different types of attachments would show similar retention loss.

MATERIALS AND METHODS

Type, material and location of four different attachments
Four commonly used attachment types (Servo-Dental, Hagen-Halden, Germany), which could be cast in both precious and non-precious alloys, were selected for this study. They were: Servo vertical ball (coded B; PB;

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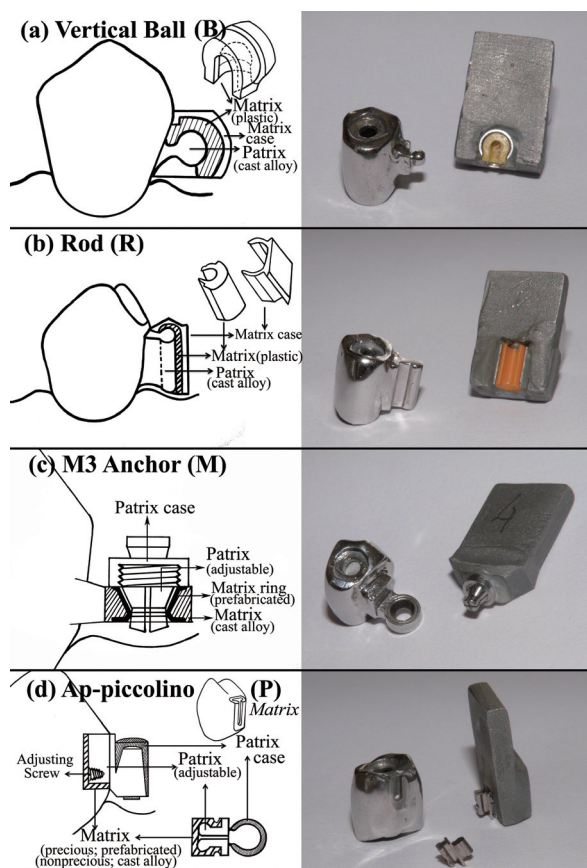


Fig. 1 Schematic cross-sectional view and photograph of each attachment system tested in this study.

precious, NPB: non-precious), Servo rod (coded R; PR: precious, NPR: non-precious), Servo M3 stud (coded M; PM: precious, NPM: non-precious), and Servo AP-Piccolino (coded P; PP: precious, NPP: non-precious). Figure 1 shows the schematic cross-sectional view and photograph of each attachment type tested in this study. Table 1 lists the detailed information of each attachment system.

B and R attachments are extracoronal attachments made of a burnout plastic which could be used with all dental alloys. Their matrices were made of a permanently elastic acrylic material and which were replaceable. The matrices were attached to the RPD while the patrices were attached to the crown.

M attachment was an extracoronal and adjustable attachment. Its matrix was made of a burnout plastic which could be used with both precious and non-precious metal alloys. Its patrix was made of titanium. P attachment was an individually activated intracoronal attachment with a removable patrix. Like M attachment, P attachment had a titanium-made patrix. The matrices of P attachment were made from two types of materials: a burnout plastic for non-precious alloy casting or prefabricated gold alloy (high-fusing Heraplat alloy, HFA). Both M and P attachments had matrices attached to the crown and patrices attached to the RPD.

Specimen preparation

Tooth model of a first premolar with 3-degree axial taper and a chamfer finish line was made out of wax (Bego Crown Wax, Bremer Goldschlägerei Wilh. Herbst, Bremen, Germany). After investing and casting the

Table 1 Details of eight attachment systems according to design type and production material

Attachment	n	Matrix	Patrix	Type	Friction Type	Batch Number
PB	6	plastic ⁺ -yellow-replaceable	cast alloy*	Extracoronal Semiprecision	Plastic-metal Resilient ⁺⁺	Matrix: PO807000509 Patrix: PO810000969
NPB	6	plastic ⁺ -yellow-replaceable	cast alloy**	Extracoronal Semiprecision	Plastic-metal Resilient ⁺⁺	Matrix: PO807000509 Patrix: PO810000969
PR	6	plastic ⁺ -orange-replaceable	cast alloy*	Extracoronal Semiprecision	Plastic-metal Resilient ⁺⁺⁺	Matrix: 734243 Patrix: 07391F05-1108
NPR	6	plastic ⁺ -orange-replaceable	cast alloy**	Extracoronal Semiprecision	Plastic-metal Resilient ⁺⁺⁺	Matrix: 734243 Patrix: 07391F05-1108
PM	6	prefabricated ring (HFA ^{***})	titanium-adjustable	Extracoronal Precision	Metal-metal Rigid	Matrix: 408102400 Patrix: 408102400
NPM	6	prefabricated ring (NPA ^{****})	titanium-adjustable	Extracoronal Precision	Metal-metal Rigid	Matrix: 408102400 Patrix: 408102400
PP	6	prefabricated (HFA ^{***})	titanium-adjustable	Intracoronal Precision	Metal-metal Rigid	Matrix: R1103/08-2718 Patrix: 108100902
NPP	6	cast alloy**	titanium-adjustable	Intracoronal Semiprecision	Metal-metal Rigid	Matrix: 541701 Patrix: 108100902

⁺Made of permanent elastic, highly precise acrylic material ⁺⁺Resilient by design ⁺⁺⁺Resilient by plastic matrix (orange)

*Albabond EH, Heraeus Kulzer, Hanau, Germany **Heraenium P, Heraeus Kulzer, Hanau, Germany

High-fusing Heraplat alloy, castable to precious metal alloys *Non-precious alloy, castable to all alloys without precious metal

wax pattern, a first premolar tooth specimen made of a metal alloy was obtained. A screw access hole was prepared on the occlusal surface of the metal tooth to retain the crown restoration without using cement. The root part of the metal tooth was vertically embedded in the center of an acrylic resin block (Meliodent, Heraeus Kulzer, Hanau, Germany), with its long axis perpendicular to the base of the block.

The model of the crown, to which was attached the patrices of B and R attachments and the matrices of M and P attachments, was made of a modeling wax (Dentalwachse Casting wax, Karl Berg, Engen, Germany). The attachments were attached to the wax crown by using a surveyor (APF400, Amann Dental Equipment, Koblach, Austria). Before investing and casting, screw sockets were prepared on the occlusal surfaces of the wax crowns. For each attachment system, six attachment-holding crowns were prepared. Therefore, a total of 24 non-precious (Heraenium P, Heraeus Kulzer) and 24 precious metal alloy (Albapond EH, Heraeus Kulzer) crown specimens were prepared.

Retention force measurement

For each attachment system, six specimens were prepared for the retention test. Retention force of each attachment was measured by using a specially designed insertion-separation machine (Festo AG & Co., Istanbul, Turkey), which acted as a wear simulator for insertion-separation movements and as an Instron testing machine during retention force measurements.

Each attachment-retained crown specimen was screwed to a metal tooth, which was vertically embedded at the center of an acrylic resin block and surrounded with a clear container. A parallelometer (APF400, Amann Dental Equipment) was used to place the matrices of B and R attachments and the patrices of M

and P attachments on the holder of the moving part of the insertion-separation machine (Fig. 2). The acrylic resin block and attachment holder were then fixed after adjusting the patrix and matrix to be parallel aligned.

To ensure that the attachment remained completely submerged in water during the retention test, insertion and separation movements were performed in an axial direction in distilled water of approximately 25°C (Fig. 3). Duration of one complete wear-simulating insertion-separation cycle was approximately 2.5 s. Retention force was measured at the beginning of and after 10, 100, 500, 1000, 2500, 5000, and 10000 insertion-separation cycles. During retention force measurements, tensile load was applied at a crosshead speed of 10 mm/min and the peak load to dislodgement was measured as the retention force.

Statistical analysis

Eight sets of insertion-separation cycles were carried out in this study: 0, 10, 100, 500, 1000, 2500, 5000, and 10000. For each attachment system, six specimens were tested. The mean and standard deviation values of retention force for each attachment system ($n=6$) were recorded for all the eight sets of insertion-separation cycles.

Within each set of insertion-separation cycles, differences in retention force among the attachment systems were examined using one-way analysis of variance (ANOVA). At the end of the test (10,000 cycles),

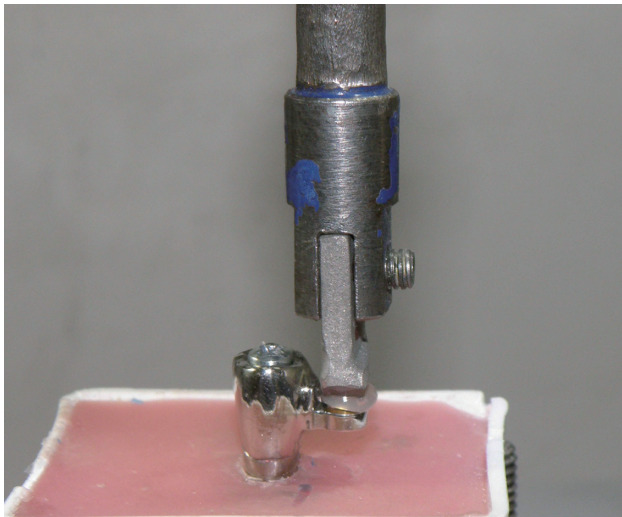


Fig. 2 Patrix of M3 attachment placed on the holder of the moving part of insertion-separation machine.

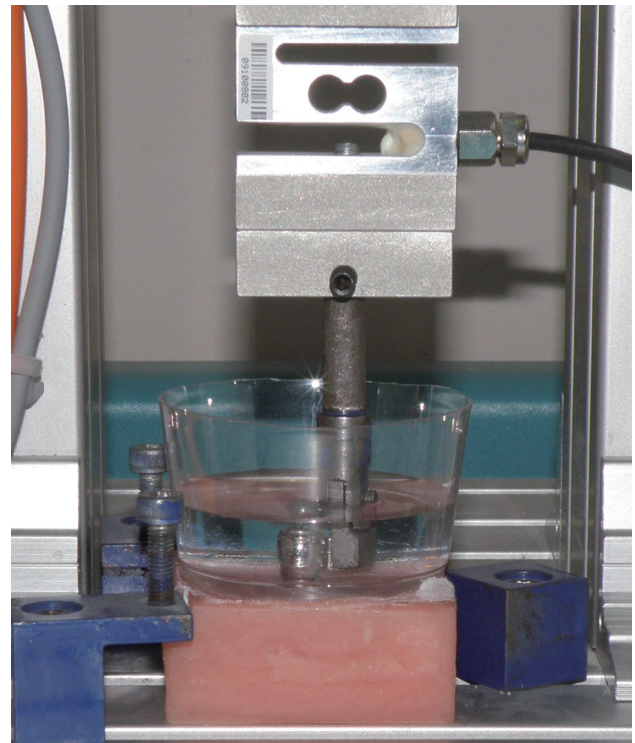


Fig. 3 Retention test setup.

change in retention force for each attachment system when compared to the beginning of the test (0 cycles) was evaluated by repeated measures ANOVA. Tukey's comparison test was used to compare the retention force values of the different attachment systems at 0.05 level of significance. The *t*-test was used to evaluate the difference between the precious and non-precious types of the same attachment system.

RESULTS

Table 2 shows the mean and standard deviation values of retention force for all the attachment systems for each set of insertion-separation cycles. Statistical

correlation for the change in retention force was also given for each attachment system.

At the beginning of the test (*i.e.*, 0 cycles), the most retentive attachments were PP (24.51 (1.09)) and NPP (22.61 (1.53)). The lowest retention values were recorded for R attachment system (PR=0.75 (0.13), NPR=1.12 (0.09)). One-way ANOVA showed that there were significant differences in retention force among the attachments at the beginning of the test ($p=0.0001$). Attachments with and without significant differences are shown in Fig. 4.

After 10,000 insertion-separation cycles, the retention forces of all attachments became significantly decreased ($p=0.0001$). PM had the highest retention

Table 2 Retention force values (mean and standard deviation) of all attachment systems at each set of insertion-separation cycles and repeated measures ANOVA results

Attachment	0	10	100	500	1000	2500	5000	10000	<i>p</i>
PB	4.85 (0.93)	4.51 (0.80)	4.25 (1.02)	1.83 (0.45)	1.01 (0.20)	0.50 (0.12)	0.18 (0.04)	0.08 (0.01)	0.0001
NPB	3.82 (0.93)	3.36 (0.87)	3.18 (0.74)	1.52 (0.19)	0.74 (0.14)	0.22 (0.03)	0.12 (0.01)	0.06 (0.01)	0.0001
PR	0.75 (0.13)	0.83 (0.12)	1.29 (0.27)	1.81 (0.41)	1.80 (0.46)	1.53 (0.35)	1.19 (0.32)	0.80 (0.14)	0.0001
NPR	1.12 (0.09)	1.27 (0.23)	1.98 (0.43)	2.05 (0.49)	1.70 (0.42)	1.41 (0.39)	0.97 (0.26)	0.76 (0.21)	0.0001
PM	17.38 (4.78)	19.84 (4.74)	17.86 (1.96)	13.04 (3.52)	12.89 (3.84)	13.09 (4.53)	12.76 (4.23)	12.60 (4.01)	0.0001
NPM	10.09 (0.83)	10.79 (0.78)	16.19 (0.98)	17.77 (0.92)	16.09 (1.11)	13.07 (0.72)	10.32 (0.68)	7.75 (1.01)	0.0001
PP	24.51 (1.09)	24.53 (0.73)	17.34 (1.46)	13.99 (2.90)	7.35 (0.82)	5.20 (0.68)	3.64 (0.42)	2.28 (0.58)	0.0001
NPP	22.61 (1.53)	19.75 (1.44)	4.21 (0.60)	1.50 (0.22)	0.58 (0.10)	0.32 (0.06)	0.17 (0.03)	0.08 (0.01)	0.0001

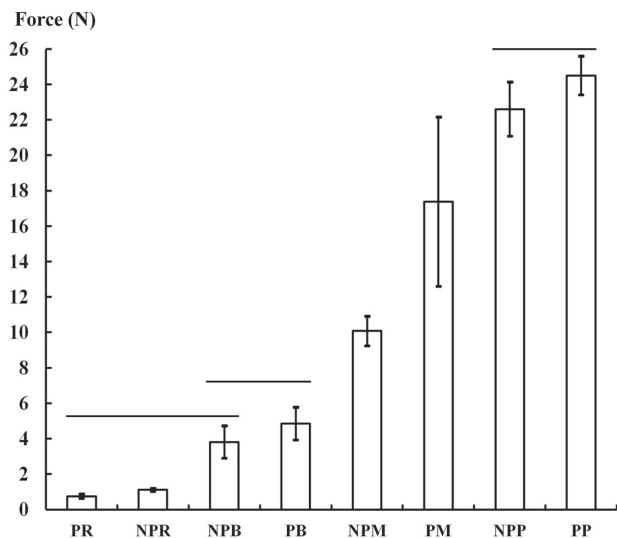


Fig. 4 Initial retention force values of four precious and four non-precious attachments at 0 cycles (means and standard deviations). Attachments without significant differences are linked with horizontal bars ($p>0.05$).

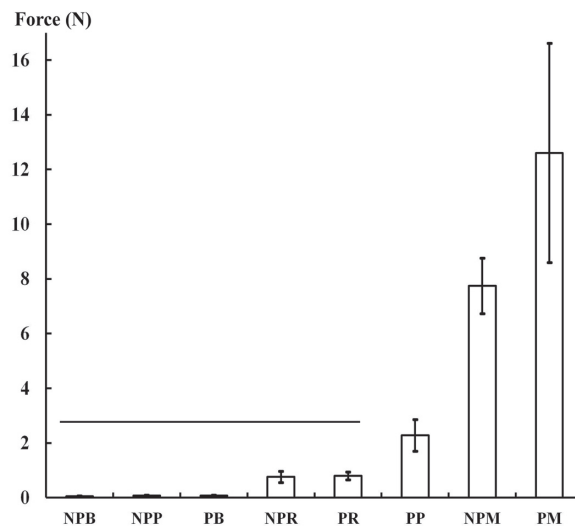


Fig. 5 Retention forces of four precious and four non-precious attachments after 10,000 cycles (means and standard deviations). Attachments without significant differences are linked with a horizontal bar ($p>0.05$).

force (12.60 (4.01)) after 10,000 cycles, but the lowest retention force values were recorded for PB (0.08 (0.01)), NPB (0.06 (0.01)), and NPP (0.08 (0.01)). Significant differences in retention force among the attachments after 10,000 cycles are presented in Fig. 5.

Figure 6 shows the retention behaviors of four precious and four non-precious attachment systems for each set of insertion-separation cycles. R and M attachments exhibited similar behavior in that both showed an initial increase during the first 100–500 cycles, followed by a decline in retention force. For B and P attachments, their retention behaviors were on the decline from the beginning of the test.

Comparison of the precious and non-precious types of the same attachment system by *t*-test revealed that there were no statistically significant differences between these two materials for B and R attachment systems. However, significant differences were found for M and P attachment systems ($p \leq 0.05$). Precious types of both M and P attachments (PM, PP) showed

higher retention force values than the non-precious types (NPM, NPP) after 10,000 insertion-separation cycles. The differences between the precious and non-precious types of each attachment system are listed in Table 3.

DISCUSSION

Attachment-retained RPDs are provided with varied retentive properties according to different attachment designs. However, studies have shown that attachments of similar designs differed in wear mechanism and retention behavior^{1,4,7,8,10-12}. This *in vitro* study measured the changes in retention force of four types of attachment systems with different initial retention capacities. After 10,000 insertion-separation cycles, patterns in retention changes among the different attachment designs during the course of retention test were identified. The effects of attachment design and production material on retention behavior were investigated. Based on the results of this study, the hypothesis that four different types of attachments would show similar retention loss was rejected.

In recent years, growing interest in implant-supported dentures has fuelled many studies on the retention characteristics of attachments used for implant-supported dentures^{13,14}. However, because of low cost and inadequate remaining alveolar bone, traditional RPDs are still the preferred treatment choice for many patients. A fixed-removable denture combines the stabilizing qualities of a fixed partial denture with accessibility to the tissues of a RPD. It also boasts of several economical, anatomical, and psychological benefits over implant-supported fixed dentures¹¹. To ensure patient satisfaction with adequate denture retention and optimum esthetic outcome, many types of attachments can be used with dentures: extracoronal or intracoronal, precision or semi-precision, precious or non-precious.

Denture retention could be compromised because of abrasion effects on attachment materials. To permit comparisons under standardized conditions, many studies in *in vitro* settings have been carried out to investigate the long-term retention and wear behavior of attachments^{5,8}. In the present study, the wear test was based on 10,000 insertion-separation cycles. The

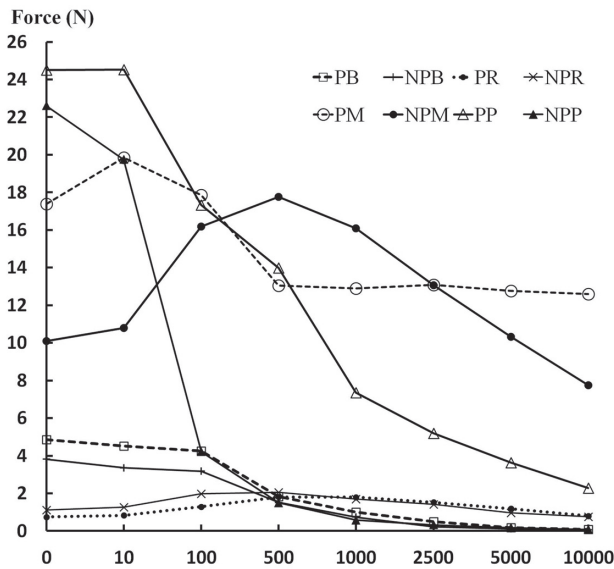


Fig. 6 Retention behaviors of eight attachment systems at each set of insertion-separation cycles.

Table 3 Statistical differences (*p* values), according to *t*-test, between the precious and non-precious materials of each type of attachment

Attachments	0	10	100	500	1000	2500	5000	10000
PB-NPB	*	*	*	*	*	*	*	*
PR-NPR	*	*	*	*	*	*	*	*
PM-NPM	0.013	0.005	*	0.020	0.011	*	*	0.0001
PP-NPP	*	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

*: $p > 0.05$

assumption was that if a denture were to be removed and replaced three times daily for cleaning, then 10,000 insertion-separation cycles would correspond to a clinical life of approximately 10 years.

Others factors that affect the retention of attachments are namely, salivary composition, temperature of the food consumed, and calculus accumulation^{11,15}. Artificial saliva was used as a lubricant in some *in vitro* wear simulation studies, and SEM photographs revealed the presence of crystalline deposits on the attachment surface, which accelerated the wear of attachments^{4,11}. To avoid the formation of crystalline deposits derived from artificial saliva, some researchers have used distilled water instead^{12,16-18}. To exclude the influence of deposit accumulation on attachment surface so as to ensure standardized *in vitro* experimental conditions, distilled water was used in this study.

According to Wang *et al.*¹, different types of attachments resulted in different biomechanical effects on terminal abutment teeth and the supporting tissues. They reported that loading on abutment tooth was higher with a rigid attachment than with a resilient attachment¹. Therefore, rigid attachments are recommended for tooth-supported RPDs and resilient attachments for distal-extension RPDs¹. In the present study, it was also observed that different attachment designs provided different retention characteristics. For R and B attachments, they exhibited low initial retention capacities at *circa* 1 N and 4 N respectively. This could be attributed to the fabrication tolerances of the retentive elements. Both R and B were semi-precision and resilient attachments: their matrices were produced by casting method and their matrices were made of plastic. M and P attachments had higher initial retention capacities than B and R attachments: above 10 N for M and above 20 N for P. Both M and P were precision and rigid attachments which had prefabricated matrices and matrices. With M attachment, the retentive ring of the matrix was prefabricated; the remaining part of the matrix was made of burnout plastic, which was also produced by casting method.

According to Wolf *et al.*¹², frictional contact between attachment components resulted in increased surface roughness of the retentive parts, which in turn resulted in an initial increase in retention force. As for Holst *et al.*¹⁹ who investigated the retention forces of metal precision attachments, they reported that friction between the matrix and matrix led to an increase in the size of contacting surfaces, which in turn caused an initial increase in the retention forces of precious attachment systems. In a wear behavior study by Wichmann and Kuntze⁴ which simulated wear using insertion-separation cycles, they reported that water absorption and/or thermal expansion of the plastic part caused an initial increase in retention force for an attachment with a plastic matrix. In the present study, R (plastic-metal friction) and M (metal-metal friction) attachments systems also showed an initial increase in retention force at the beginning of the retention test^{4,12}.

In contrast, the retention force values of B (plastic-metal friction) and P (metal-metal friction) attachments decreased since the beginning of the retention test.

Over time through the course of the wear simulation test, Wichmann and Kuntze⁴ reported that attachments with metal-to-metal friction showed a higher retention loss than attachments with plastic inserts⁴. However, Hedzelek *et al.*¹¹ reported that the wear resistance of attachments with metal-to-metal friction was higher than those with plastic inserts. Among metal precision attachments, Holst *et al.*¹⁹ reported that machined, high-noble gold alloys show less wear than cast metals (such as titanium). In the present study, mixed and contrasting results were observed. R cast attachment system with plastic matrix and M machined precision attachment system with metal-to-metal friction showed a lower retention loss (0%–32.1% reduction of initial value) than B cast attachment system with plastic matrix and P machined precision attachment system with metal-to-metal friction (90.7%–99.6% reduction of initial value). The underlying reason could be due to the different designs of the attachment systems.

In the present study, precious and non-precious attachment component materials resulted in different retention behaviors for each type of attachment design. For B and R attachments, their retention forces were not affected by the material used. This was probably because both B and R attachments had plastic matrices in contact with metal alloy matrices. M and P attachments had metal-to-metal friction. After 10,000 insertion-separation cycles, precious types of both attachments (PM, PP) showed higher retention force values than the non-precious types (NPM, NPP). Moreover, there was a significant difference in final retention force values between PP and NPP, which could be attributed to the fabrication method. The matrix of NPP attachment was fabricated by casting method. Therefore, inaccuracies inherent in fabrication by casting might have affected the retention capability of NPP attachment.

Location of denture attachments is another influencing factor to attachment retention. Intracoronary attachments favor direct load transmission to the abutment teeth: occlusal forces axially exerted upon the abutment teeth are applied close to the long axis of the teeth and directed parallel along the long axis of the abutment teeth. For extracoronary attachments, occlusal forces are applied far from the long axis of the abutment teeth^{1,20}, which could cause a harmful effect on abutment teeth. In the present study, the dislodgement force was applied vertically or axially for attachment insertion and separation without applying any force to the abutment. Therefore, difference in retention behavior between intracoronary and extracoronary attachments was not a distinctive factor in this study.

In the clinical setting, non-axial forces affect the wear mechanism and retention of attachments. An extension of the lamella of plastic matrix of cylindrical attachments, a fracture of the matrix neck of ball attachments, or irregular wear processes were all due

to non-axial loading. Indeed, many factors can affect the retention of attachments in a clinical situation. However, it is difficult to standardize clinical studies to investigate material- and design-dependent retention behavior. Results of this study are limited to *in vitro* comparisons. Further studies are necessary to test the attachments clinically and compare the *in vivo* retention behaviors of attachments with *in vitro* laboratory results.

CONCLUSIONS

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

1. Retention loss was observed for all types of attachment systems.
2. R and M attachment systems showed an initial increase in retention force, but B and P attachment systems showed declining retention from the beginning.
3. PM attachment, which was a precious, precision, and metal-to-metal friction type of attachment, emerged as the most retentive attachment after 10,000 insertion-separation cycles.
4. Attachments with metal-to-metal friction showed higher retention force values than attachments with plastic inserts.
5. Type of metal alloy was critical in the retention of attachments with metal-to-metal friction. Friction between precious metal alloys caused lower retention loss than with non-precious metal alloys.

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