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Effects of Long-Term Simulated RPD Clasp Attachment/Detachment on Retention and Wear for Two Clasps and Three Abutment Material Surfaces

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1. Introduction

Although removable partial dentures (RPDs) are favored options for the restoration of many situations that involve partial tooth loss, some patients are not satisfied with a removable partial denture (RPD), especially when it is not stable during mastication (Bezzon et al. 1997). As a result, sufficient retention of RPDs is considered one of the important factors that affect the clinical success of the RPDs. Two types of direct retainers (intracoronal and extracoronal) are most commonly used in dental practice. Using the extracoronal direct retainer has many advantages than intracoronal direct retainer. They are easily constructed, easily repaired, not expensive, do not require severe preparation (Phoenix et al. 2003), and its retentive arm can be covered by composite resin to enhance its esthetic (Ikebe et al. 1993). Retention of RPDs is accomplished by placing clasp parts into undercuts on abutment teeth. The integrity of the enamel surface upon which retainers are placed affects the service ability of the prosthesis.

The retention of RPD is defined as the ability of a fully seated RPD to resist dislodging forces (Johanson et al. 1983). Retention usually is achieved by using mechanical means such as clasps which engage undercuts on the tooth surface, harnessing the patient’s muscular control acting through the polished surface of the denture, and using the inherent physical forces which arise from coverage of the mucosa by the denture (Davenport et al. 2000). Phoenix et al. (2003) defined RPD retention as the quality of the clasp assembly that resists forces acting to dislodge components away from the supporting tissues. Boucher and Renner (1982) defined the clasp as the component of a RPD, which acts as direct retainer, and stabilizer, or both for the denture by partially encircling or contacting the abutment teeth. Also the direct retainer is defined as that component of a RPD that is used to retain and prevent RPD dislodgement (Academy of Prosthodontics 2005).

A successful RPD retainer must prevent displacement of the prosthesis in four directions. Vertical displacement must be counteracted when forces act from an occlusal to gingival direction and from a gingival to occlusal direction. Lateral displacement must be counteracted when forces act from right to left and from left to right. To fulfill these requirements a retainer should provide means of primary retention, vertical force transmission, and occlusal force transmission (Blaterfein 1969). All clasp assemblies must be designed so that they satisfy the following six requirements: 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, 5) Encirclement: Engages the tooth greater than 180° to prevent horizontal tooth movement from within the confines of a clasp assembly, 6) Passivity: Puts no active force on a tooth when a clasp is in place (Phoenix et al. 2003, Jones and García 2009).

There are many factors affecting the retention of the extracoronal direct retainers (clasps). Applegate (1965), Osborne and Lammie (1974), Korl (1976), and Henderson and Steffel (1981) listed four factors to be considered in determining the amount of clasp retention to be used, these factors are the angle of infrabulge convergence, the distance below the height of contour, the accuracy of adaptation to the contacting surface, and the flexibility of the clasp arms. The retention of RPD clasp depends upon the following features: (1) number and position of the saddles and the guiding planes, (2) mobility of the teeth, (3) mechanical properties of the alloy, (4) dimensions of the clasps; shape, length, and taper, and (5) design of clasps (Bates 1980). The dislodging force was dependent on the fit of the framework, the depth of the undercut, the number of the clasps, and its point of application (Ahmed et al. 1992). However, La Vere (1993) listed five factors that determine clasp retention, and summarized them in the following three categories (1) the fit of the clasp to the abutment, (2) the flexibility of the retentive arm, and (3) the condition of the abutment.

Others investigated the effect of clasp material on the retention force of the clasp. Bates (1965) studied the mechanical properties of cobalt chromium alloys (Co-Cr) and their relation to RPDs. The author reported that the minimum undercut to be tested for the Co-Cr alloys should be 0.25 mm and the clasps should be at least 15 mm long. Where undercuts greater than 0.25 mm are available on the teeth, a gold clasp is to be preferred, since it has adequate flexibility and a safety margin not available with Co-Cr alloys. The significant differences exist in the fatigue resistance of RPD clasps made from different commercial cast metals, which may cause loss of retention of the RPD and clasp failures (Vallittu and Kokkonen 1995). While Bridgeman et al. (1997) compared titanium and cobalt-chromium RPD clasps, they mentioned that the long-term retentive resiliency of the pure titanium and titanium alloy clasps suggests that these materials are more suitable for RPDs than cobalt-chromium. Also Rodrigues et al. (2002) compared circumferential RPD clasps (E-clasps) made of commercially pure titanium and identical clasps made of two different cobalt-chromium alloys by testing insertion/removal and radiographically inspecting the casts for defects. The authors suggested that commercially pure titanium clasps maintained retention over a simulated 5-year period, with lower retention force than identical cobalt-chromium clasps. However Kim et al. (2004) investigated the retentive force of various types of clasps during repeated cycles of placement and removal to determine whether titanium alloy clasps maintain their initial retentive force under varied conditions, including different retentive undercut depths and clasp size. The authors concluded that although the end-point retention for all the clasps was similar, there was less change in the retentive force of the cast titanium alloy clasps after repeated cycling sequences of simulated placement and removal. On the other hand Cheng et al. (2010) showed that after a test simulating 5 years of service, cast Co-Cr alloy clasps exhibited a residual retentive force to satisfy the requirements for clinical use. While others reported that frameworks fabricated in commercially pure titanium tend to decrease in retentive strength over time and have a potential risk of fracture in less than 0.75 mm of undercut (Souza et al. 2011).

Jochen (1972) recommended the use of planned parallel guiding planes for RPDs. The most important consideration is that the guiding plane retention has less potential for causing supporting structure damage than does clasp retention (Holt 1981). Also the guide planes could be a mean of providing additional frictional resistance and therefore contribute to the retention of a RPD (Stewart et al. 1983). Moreover Stern (1975), Krikos (1975), and Holt (1981) studied the effect of guiding planes on reciprocation and retention. They stated that two factors that may improve retention and reciprocation in clasp design are the length of the guide plane, corono-gingivally to adequately reciprocate the action of the retentive arm and the relationship of the undercut to the guide plane as a means of increased retention. Sato and Hosokawa (2000) discussed the importance of guiding planes and proximal plates for conventional tooth-supported RPDs with circumferential clasps, they stated that the guiding plane should be parallel to the path of insertion and must be of an adequate length for sufficient retention.

The flexibility of the retentive clasp arm plays an important role in determining the amount of retention of the retentive clasp arm. There are various factors affecting and controlling the flexibility of the retentive clasp arm, including composition, gauge, length, curvature, and cast or wrought structure (Bates 1963, Bates 1965, Clayton and Jaslow 1971, Frank and Nicholls 1981, Frank et al. 1983).) The flexibility of clasp arm is determined by its length, diameter, form, structure, torsion of the arms of the clasp, and by properties inherent in the alloy used (Applegate 1965). The cast 18-gauge wire clasp is 14% stiffer than a wrought wire clasp of the same gauge and alloy, and the flexibility is a function of composition, gauge, taper, and length of wire (Morris et al. 1981a, 1981b, 1983). The acceptable amount of retention for a bilateral distal extension RPD ranges from 2.9 N to 7.3 N, 20-gauge wires are twice as flexible on the average as 18-gauge wires, and wires having different alloy compositions exhibit differences in flexibility (Frank and Nicholls 1981). The prime reason for using a wrought wire retentive clasp arm is to provide more flexibility than that afforded by a cast clasp arm. An increased flexibility permits deeper undercuts engagement, allows easier adjustment of the clasp arm, and reduces loading of an abutment tooth during insertion and removal of RPDs (Stade et al. 1985). The flexibility is a factor that can be regulated very easily for controlling the retention force of a clasp and the flexibility of the clasp is affected by the clasp dimensions and the mechanical properties of the constituent alloy (Yuasa et al. 1990). The length of the wrought wire appeared to be less important than the curvature of the clasp as a factor in flexibility (Clayton and Jaslow 1971). On the other hand, Snyder and Duncanson (1992) stated that the degree of permanent deformation of the clasp was not related to clasp form or width-thickness ratio.

The types of RPD clasps are either occlusally approaching clasps or gingivally approaching clasps or combination clasps. The roach type clasp (gingivally approaching clasp) has a long gingivally approaching retentive arm, so it has less bracing action and more retentive action than the shorter arm of three-arm clasp (Osborne and Lammie 1953). The gingival approaching clasps are probably easier to design and make more flexible as the length of the arm can be increased with very little change in the design of the denture (Bates 1980). Only the terminal third of an occlusally approaching clasp should cross the survey line and enter the undercut area, while a gingivally approaching clasp contacts the tooth surface only at its tip, the reminder of the clasp arm is free of contact with the mucosa of the sulcus and the gingival margin. The length of the gingivally approaching clasp, unlike the occlusally approaching, is not restricted by the dimensions of the clasped tooth. The length of gingivally approaching clasp can therefore be increased to give greater flexibility which can be a positive advantage when it is necessary to clasp a premolar tooth. However, the occlusally approaching clasp is more rigid and most of it is in contact with the tooth surface above the survey line than gingival approaching clasp (Davenport et al. 2000). The gingivally approaching clasp is an appropriate choice under such circumstances as it can be made long enough to achieve adequate flexibility. Canine and premolar teeth obviously vary in their mesiodistal dimension but are generally of the order of 7 mm. A cast cobalt-chromium occlusally approaching clasp may be a little longer than this. However, this may not be long enough to ensure that such a clasp has adequate flexibility and is working within its proportional limit. Therefore, on such teeth, more effective and reliable clasping can be obtained either by utilizing the longer gingivally approaching clasp or by using wrought wire retentive clasp arm (Davenport et al. 2001).

Various clasp designs had been discussed and recomended by many authors (Pezzoli et al. 1993, Igarashi et al. 1999, Aoda et al. 2010). Clayton and Jaslow (1971) reported that the force exerted by wrought wire clasp during removal of the casting was 6.9 N and that for bar clasp ranged from 5.1 N to 6.9 N. The most often used clasps are the wrought wire circumferential clasp which engages a mesiobuccal undercut, one half T-bar clasp which engages a distobuccal undercut, and I-bar cast clasp which engages an undercut just apical to the mesiobuccal height of contour (McCartney 1981). However, the RPA clasp design (which consists of mesial rest R, proximal plate P, and retentive Aker arm A) has some advantages over the RPI clasp design (which consists of mesial rest R, proximal plate P, and retentive I-bar arm I). The circumferential-type retentive arm is easier to grasp for removal of the prosthesis, the RPA clasp is simple in design with few variations among patients, the circumferential retentive arm avoids the tissue problems around abutment teeth and allows the RPA clasp to be used in many situations where the RPI clasp is contraindicated, especially in case of when a buccal undercut is absent, severe tissue undercut to avoid food or tissue trap, or in shallow vestibule (Eliason 1983). Aviv et al. (1990) favored RLS clasps, which consist of a mesial occlusal rest, a distolingual L-bar direct retainer that is located on the abutment tooth adjacent to the residual ridge, and a distobuccal stabilizer distal extension RPD. Also others used the hinged clasp assembly RPD in case of severe undercuts and malpositioning of teeth, which can create problems with the path of placement of RPD (Campbell and Weener 1990, Cameron and Lyons 1996). However, Sato et al. (2001) stated “the I-bar clasp is one of the most popular direct retainers for distal-extension RPDs”. I-bar clasp consists of I-bar clasp bar retentive clasp arm, occlusal rest, lingual circumferential clasp arm as bracing arm, and proximal minor connector. The bar type clasp is said to have a push type retention while the circumferential one is said to have a pull type retention. The retentive arm of an infrabulge clasp is significantly longer than the retentive arm of suprabulge clasp assembly. Consequently, the expected retentive force may be negated by the increased flexibility of the infrabulge arm (Phoenix et al. 2003).

The back action clasp and E-clasp are occlusal approaching clasps but they are different in their designs, from the retentive point of view it is wise in chrome-cobalt work to use direct retainers of the RPDs whose retentive section is placed at some distance from the point of attachment of the clasp to the framework of the denture, in order to allow a bigger moment to act. Such long-arm direct retainers are, of course, the roach, back action, reverse back action, modified ring and extended arm varieties (Osborne and Lammie 1953). Moreover, Firtell (1968) investigated the effect of clasp design upon retention of RPDs, the author measured the retention of varying clasp designs. The results reported for U–infrabulge was 28.5 N, that for Aker’s was 13.7 N, that for Aker’s (wrought gold wire retentive arm) was 12.5 N, that for I–bar (gold wire) was 7.6 N, and that for back action clasp was 1.6 N. Aker’s clasp (E-clasp) is most often used in dental practice; it is composed of an occlusal rest to give support, a horizontal reciprocal arm above the survey line and a retentive arm (Henderson and Steffel 1981). Also La Vere (1993) compared RPI, RPA, modified T and Akers clasp. Each clasp was tested using natural teeth and gold crowns, in dry and wet environments. The author examined the effectiveness of each of the four types of clasps in resisting displacing forces, in both vertical (occlusal) and mesio-occlusal directions. The author found that the RPA clasp was the most retentive of all on natural abutments, against both directions of pull, but only slightly so over the RPI clasp with a vertical pull. However Soo and Leung (1996) studied the retention of hidden clasps, and compared it with that of Aker's clasps and I bars when they function as part of a tooth-supported partial denture framework. The mean retention forces for the whole framework were 17.5, 7.6, and 13.1 N for the Aker's clasp, I bar, and Hidden clasp, respectively. They reported that the hidden clasp had the greatest variability in retention among the three groups tested.

Retention of RPDs is accomplished by placing clasp parts into undercuts on abutment teeth, when a natural undercut cannot be located with a surveyor, it may be created by crowns, a class V restoration, cementation of a wire, recontouring of enamel (dimpling), and recontouring with resin (Holmes 1968, Jenkins and Berry 1976, Leupold and Faraone 1985, Hebel et al. 1984, Zarrati et al. 2010). The direct retention by clasps is possible only when the appropriate horizontal undercuts are present for specific path of insertion, the horizontal undercut can be modified by altering the height of contour, but it must be not infringe on the gingival tissue. The retentive clasp tip should be placed in the gingival third of the coronal surface to lower the fulcrum point and reduce the tipping forces on the abutment tooth (Seals and Schwartz 1985).

Krikos (1969) described a method for establishment of an artificial undercut for teeth, which have unfavorable shapes for clasping by using threaded wire, this threaded wire was cemented within artificial pinhole. While McCartney (1981) modified the labial surface of the enamel by preparing 1mm dimple in the center of the distal half of the labial surface, gingival to height of contour, in which the wrought wire I-bar retentive clasp arm ends. The prepared area should have the same general outline as the retentive tip of the clasp arm, which will fit into it. Therefore, the term should be recontouring not dimpling to establish a retentive area (Axinn 1975). However, Crowther et al. (1981) mentioned that a channeled groove is preferred rather than a dimple, therefore the tooth preparation conforms to the shape of the distal third of the clasp. When viewed in the labial-lingual section the preparation will appear as a half round contour, if left unmodified the clasp arm will travel over the enamel and make an accelerated snap into undercut. Also the distofacial ridge may be placed on the distofacial surface of the canine as part of a pin-modified metal inlay, built into the design of ceramometal restoration, or erected with composite after etching the underlying enamel surface, ceramometal restoration is used when caries or large restorations are present on the canine (Hansen and Iverson 1986). An alternative technique had been described for recontouring cervical eroded and abraded area by using enamel fragments, in this technique the enamel fragments could be used in a manner similar to laminate veneers to provide additional clasp retention in instances where there is excessive cervical abrasion and erosion, these fragments provide esthetic restorations with excellent wear characteristics under metal RPD clasps (Carvalho et al. 1995). However Liebenberg (1995) introduced a new direct technique in which the light-curing glass-ionomer resin cement is utilized for the direct restoration of RPD abutments, for this technique the cavity preparation is completed in the customary manner and the cement is applied in masses and covered with a suitable translucent separating sheet. The denture is reinserted and the restoration is light cured, then the denture is removed, and, with the aid of a suitable disclosing medium, the restoration is trimmed carefully to avoid reducing the intimate adaptation between the restoration and RPD, this restoration would serve as an adequate interim restoration until the patient is able to afford a cast abutment restoration.

Many authors studied in vivo and in vitro the contour modifications of teeth by acid etch retained resins to create undercuts. These techniques provide minimal tooth destruction (a few microns during etching) as well as the advantages of ease of preparation, repair, and alteration (Siirila 1975, Piirto et al. 1977, Quinn 1981). The introduction of the acid-etch technique for the bonding of composite resin to enamel has provided a conservative means of modifying tooth contour to create undercuts for the retention of the RPD clasps (Davenport et al. 1990).

Many methods have been suggested to obtain retention for prosthetic appliances in the absence of the natural undercuts. Full crowns, precision attachments, and various intra-coronal devices have been used effectively, but their use necessarily involves a considerable amount of time and expertise. The introduction of acid-etch retained resins has made possible rapid modification of tooth contour without hard tissue destruction, it is, therefore, possible to produce clinically useful degree of undercut (Jenkins and Berry,1976). Latta (1990) used the composite resin for contouring of abutment teeth, which have unfavorable contour for rotational path RPDs. The modification of the tooth contour with composite resin is a conservative, simple, durable and effective way of creating undercut for clasping where no, or inadequate undercut exists (Davenport et al. 2001). While Pavarina et al. (2002) and Varjão et al. (2012) described a technique in which light polymerized composite material is used to obtain retention for RPD retainers when usable natural undercuts are unavailable.

The partial-coverage porcelain laminate restorations might successfully be used to create undercuts for RPD abutment teeth (Tietge et al.1992b). Leupold and Faraone (1985) investigated the feasibility of using electrochemically etched castings bonded to etched enamel as an adjunct to mouth preparation placement of RPDs. These castings have been in service and subject to loading by the RPDs for 26 to 42 months. They reported that the bond strengths have been sufficient to support function of both castings and RPDs clinically, and none of the castings has failed in its bond. Also Elledge et al. (1989), Dixon et al. (1990), and Dixon et al. (1992) described the use of a partial coverage porcelain laminate to enhance clasp retention, the conservative partial-coverage porcelain laminate offers an esthetically pleasing and minimally invasive alternative for creating an undercut for RPDs. An insufficient buccal undercut for RPD retainer necessitated the use of an invasive procedure to correct the problem. The authors reported that the partial coverage design reduces the possibility of debonding caused by occlusal stresses or trauma and can also reduce the wear associated with composite resin.

However, others described techniques for fabricating crowns beneath existing RPDs (Killebrew 1961, Ewing 1965, Barrett and Pilling 1965, Lee 1970, Warnick 1970, Thurgood et al. 1973, Welsh 1975, Ellegde and Schorr 1990, Helvey 2002, Carracho and Razzoog 2006). Also Lubovich and Peterson (1977) fabricated ceramic-metal crown to fit a RPD direct retainer. However, Teppo and Smith (1978) used cast gold crown to fit a RPD clasp.

Many studies were carried out to investigate the effect of RPD clasps on the abutment retention surfaces. Phillips and Leonard (1956) studied the abrasion of enamel as related to the direct retainer of RPD in an in-vitro study. The authors used a cast cobalt-chromium clasp and a representative gold clasp, and attempted to duplicate conditions prevailing in the mouth. The clasps were pushed on and pulled off natural teeth coated with saliva and they considered a vibratory type of wear, which might arise when a denture is in function. The authors concluded that abrasive wear is not a significant problem in 25,000 cycles since less than 0.025 mm of material was removed. They added that no visual evidence of wear was noted on any wet specimens regardless of the clasp material. Also Bates (1968) investigated the abrasion of enamel as related to the direct retainer of RPD in a long-term in-vitro study. For this study, the extracted teeth were stored in ringers solution prior to embedding in a brass ring. The brass ring was mounted in the testing machine. Four straight clasps, 30 mm. long, were cast in Croform 5C alloy. The deflection of the clasp tip was set at 0.38 to 0.50 mm. The author measured the amount of tooth loss from the greatest curvature of the tooth before testing and after 25,000 tooth clasp contacts. The author found that the amount of wear of the teeth is slight and not likely to affect the retention. While Hebel et al. (1984) investigated enamel and composite resin wear by RPD clasps in simulated 3-years period (4,500 cycles). The wear was generally less than 20 µm as mean site value for natural enamel and demineralized enamel. The amount of enamel wear was of such a low magnitude that it did not appear to be clinically relevant. The enamel surface can withstand the wearing effect of an RPD clasp or RPD alloy more than composite resin can (Swift 1987, Alarcon et al. 2009). However Tietge et al. (1992a) reported that the mean wear produced by a RPD clasp (I-bar) contacting tooth specimens was 31.97 µm. Moreover, Sato et al. (1997) studied the effect of friction coefficient of Aker’s clasp on four abutment materials (human enamel, porcelain, type IV gold and high palladium alloys). They used different clasp materials (type IV gold, cobalt chromium alloys, and high palladium alloys) of two surface treatments (polished and sandblasted). They concluded that the retentive force increased linearly with increasing friction coefficient between the abutment material and clasp material. They recommended that the clasp should be designed, considering the friction coefficient of material combinations.

Also the effect of RPD clasp on composite resin retention surface was investigated (Humirudin and Barsby 2007), Davenport et al. (1988) and (1990) studied the abrasion between composite resins and clasps. They indicated that there was only minimal abrasion of composite resins tested but that when conventional composite resins were employed marked abrasion of the clasps occurred, and the abrasion of any of the composites tested was unlikely to cause a noticeable loss of retention in the clinical situation. Tietge et al. (1992a) investigated the amount of wear of composite resin materials (P-50 and Occlusin) and cast direct retainers (I-bars) during RPD placement and removal period of 2 years in vitro study. Results indicated that a statistical difference in the amount of mean wear between the two composite resins. The authors suggested that the selection of a resin composite resin for use as a RPD retentive undercut must be carefully undertaken to avoid excessive wear and loss of retention. In addition, Latta et al. (1997) investigated the in-vitro wear of visible light-cured restorative materials and RPD direct retainers. An aluminum test die was produced by replicating the facial contours of an extracted human molar (model), the replica's cervical contour was modified by placement of a restorable Class V cavity preparation. The restorative materials tested were Z100 (fine particle filled resin composite), Silux Plus (microfilled resin composite), and Photac-Fil (hybrid glass ionomer). The results of this study revealed that the retainers with round profiles caused less wear of the restorative materials than those featuring flat contact surfaces. Wear of the materials ranged from 14 ± 5.5 μm (Silux Plus by cast round) to 70 ± 10 μm (Photac-Fil by cast half round).

Maroso et al. (1981) studied the wear of porcelain when subjected to functional movements of retentive clasp arms, the porcelain-metal crowns simulating abutment retainers for RPD clasping were used to determine the effect of RPD clasp on porcelain surface. They found that little or no change was recorded in these surface profiles, indicating that little or no wear had occurred.

Many methods had been proposed to evaluate the amount of wear of different abutment materials. Bates (1968) used a micrometer for measuring the amount of enamel loss by the effect of direct retainer. However, Hebel et al. (1984) used a scanning electron microscope (SEM) for investigation of the wear of enamel, composite resins, and direct retainers. Seghi et al. (1991) studied the wear of enamel produced by dental ceramic by using a micrometer, while Dixon et al. (1992) and Tietge et al. (1992a) and (1992b) used scanning electron photomicrographs and computer imaging to quantify wear of the I-bar tips, enamel, composite, and the contacting laminate surfaces. In contrast, Matsumura and Leinfelder (1993) and (1994), Hudson et al. (1995), and Ramp et al. (1999) used profilometer for evaluating the amount of wear of enamel and different types of composite resin. Others used SEM for evaluation of the amount of wear of the enamel which produced by different types of restorations (Suzuki and Leinfelder 1993, Magne et al. 1999).

Although the retention force is affected by wear (Sato et al. 1997), it is not yet known whether the wear differs among retention surfaces and whether the wear affects the retention of the clasp of RPDs. in addition, the available scientific data do not provide an explanation regarding the gradual loss of retention of the E-clasp and back action clasps. Therefore, the effect of wear on the retention of clasps and on the retention surface, requires further investigation. Also the long-term retentiveness of these clasps is unclear and therefore a detailed analysis of the long-term retention of E-circlet and back action clasps seems important. The null hypothesis was that the retention and wear values of the circlet (E) clasp and back action clasp on the enamel, composite resin and ceramic abutments materials at different intervals would not be different.

The purpose of this study was as follows:

1. to compare the retention of circlet (E) clasps and back action clasps against three different abutment surface materials (enamel, composite, CAD/CAM ceramic crown) during long-term simulation of attachment and detachment.
2. to measure the loss of retention and wear of two clasp types (E-circlet, back action) against three abutment materials after 16,000 simulated cycles of attachment-detachment.

2. Material and Methods

Simulation of RPD detachment was mimicked by using the chewing simulator device to constant attach and detach RPD clasps from abutments involving different materials that created undercuts for 16,000 cycles of use. Retention loads were measured before and after cycling. Wear was examined in the SEM using replicas of the abutment surfaces. Comparisons among combinations were statistically analyzed.

A pilot study had been carried out to determine the initial force of retention (Bates1963, Firtell 1968, Soo and Leung 1996). This pilot study was carried out with two types of clasp design (E-clasp, Back action clasp) on natural teeth having sound enamel surfaces to determine the initial retentive force to start this experiment. This experiment was conducted to simulate about 11 years period. If a RPD would be removed four times each day (Hebel et al. 1984, Tannous et al. 2012) for 11 years, there would be about 16,000 insertions and removals. However another study was carried out over 25,000 cycles (Phillips and Leonard 1956).

For this study thirty-three upper premolars were used, these teeth were collected and preserved in 0.1% thymol solution. The teeth were cleaned and examined to ensure that only intact noncarious nonmottled enamel was present. Each tooth was perforated mesiodistally at the middle of its root by using small round bur at high speed with a coolant. Also direct retainer holding device (DRHD) was constructed especially for this study. The DRHD consisted of (1) a vertical aluminum column, (2) a horizontal aluminum arm, (3) a specimen holder which constructed from acrylic to hold the model and (4) a testing column holder (to hold the direct retainer) connected with the vertical column (Fig. 1).

One laboratory metal model (32 mm in length, 17.5 mm in width, and 20 mm in height) was constructed, this model having hole (15 mm in depth, and 7 mm in diameter) at the end of one side of its superior surface to accommodate the root of the abutment (Cu zn 37, Messing, Richter, Germany), the hole of the metal model was filled by softened wax. Then the root of the abutment (natural tooth or metal die) was inserted into the hole however its long axis was at 90 degree to the base of the metal model and the excess wax was removed.

The metal model was duplicated by using silicon impression material (Deguform, DeguDent, GmbH, Germany) and duplicating machine (DG1, Degussa, Germany) for construction of forty-eight testing models (MCP70 alloy, HEK, Germany) as following: The metal model was removed from the mold, and the abutment (natural tooth or metal die) was removed from the metal model. In case of natural tooth a small piece of steel wire 0.5 mm in cross section was placed in the perforation of the root of the tooth to provide means of retention while the tooth inside the testing model, then the abutment was returned and fixed again in its position at the mold. While the abutment was inside the mold, fused MCP70 alloy (HEK, Germany) was poured into the mold. After the alloy had set completely, testing model was removed from the mold, then it was trimmed and finished (Fig. 2). The testing models were constructed to create an apparatus to hold the abutment within the chewing simulator. These models were constructed from rectangular metal blocks with natural tooth or metal die embedded in each model vertically till the cementoenamel junction (CEJ).

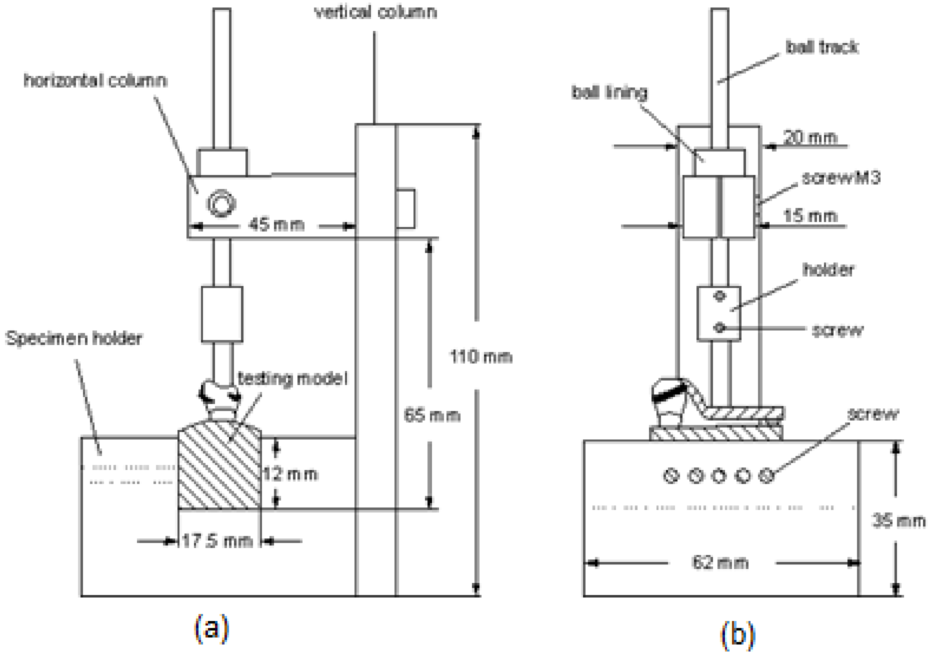

Fig. 1. Schematic diagram for DRHD: a, lateral view, and b, frontal view.

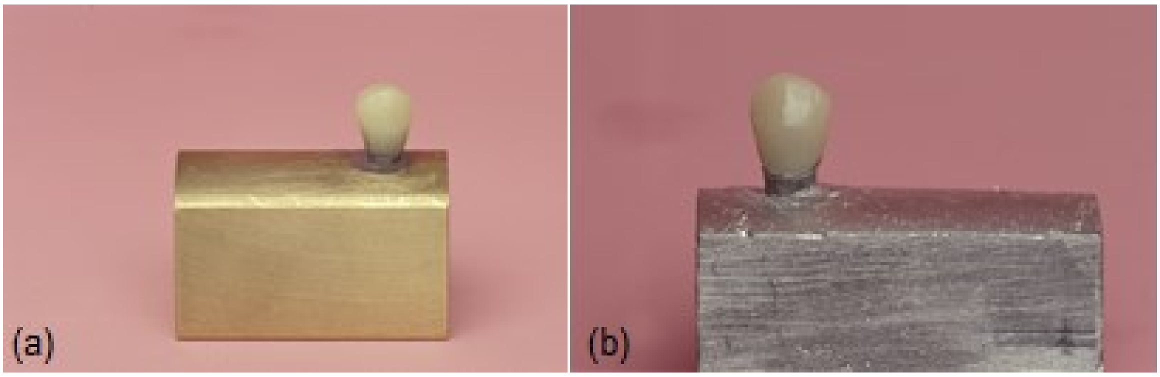

Fig. 2. a, Metal model; b, Testing model.

According to the model's teeth, they were divided into three groups. The first group (GI) consisted of 16 extracted premolar with retentive areas on their buccal enamel surfaces.

The second group (GII) had 16 premolar teeth modified buccally by composite resin (Spectrum, Dentsply DeTrey, Constance, Germany) to achieve sufficient undercut as following: The buccal surface to be clasped was etched with etching gel containing 36 % o-phosphoric acid (Conditioner 36, Dentsply DeTrey, Germany) for 45 seconds, then it was washed with water and dried with air. The primer Optibond (Kerr Corp., Orange, CA, USA) was painted over the buccal surface to be clasped for 30 seconds. Then the adhesive agent (Kerr Corp.) was applied and exposed to the light of the light curing system (Translux Ec, Heareus Kulzer, Wehrheim, Germany) for 30 seconds. The buccal surface was contoured by composite resin, then the composite resin was exposed to the light of curing system for 40 seconds for curing. The contour was adjusted and the resin was finished and polished, all procedures for recontouring the buccal surfaces of the abutments of this group with composite resin were carried out according to the manufacturer’s instructions.

For the third group (GIII) one premolar tooth had been used for construction 16 metal dies, then the dies were covered by ceramic crowns (Vita Mark II, Zahnfabrik, Germany) that constructed by using CAD/CAM (Sirona Dental system, Cerec Scan, Bensheim, Germany) as following: Mesial and distal rest seats had been prepared to the natural tooth and the palatal surface was recontoured by using stone with low speed hand piece, then tooth was powdered with titanium trioxide (Vita, Zahnfabrik, Bad Säckingen, Germany) to provide optical reflection media. Optical impression was taken for the crown of the tooth with the three dimensions Cerec 3 Camera. After that the preparation for the natural tooth was carried out to receive ceramic crown by using a medium diamond bur and then a fine one with a 4-degree taper (Komet, Gebr. Brasseler GmbH & Co., Lemgo, Germany) to achieve 2 mm axial reduction, 8-degree convergence angle, and 2 mm occlusal reduction. The fine diamond bur with a diameter of 1 mm was used to modify the depth of the shoulder (Gu and Kern 2003). Then the optical impression was taken for the crown of the tooth by using the three dimensions Cerec 3 Camera. Cerec 3 CAD/CAM system with cerec 3 software (Sirona Dental system GmbH, Cerec Scan, Bensheim, Germany) was used for designing of 16 ceramic crowns. A ceramic block (Vita Mark II, Vita Zahnfabrik) was inserted into the milling unit, and then the milling operation was started. Ready-made glaze paste was applied in thin even layer to the outer surface of the crown. The firing program recommended by the manufacturer was followed and the pre-drying temperature was 600°C. The temperature was increased 58°C/min with closing time 6 minutes. Final firing temperature was 950 °C with 1-minute holding time.

After the 16 CAD/CAM crowns had been prepared, a small metal pellet was attached to the root apex of the prepared tooth by softened wax. After that the prepared tooth with metal pellet were duplicated by using special silicon duplicating material (Speedy wax transpadupisil 101, Zahntechnik Wichnalek, Augsburg, Germany) for producing 16 metal dies. The duplicated mold was poured by melting speedy wax (Zahntechnik Wichnalek) through injector machine (Wasinjektor 1500 M, Serien-Nr. 009801, Zahntechnik Wichnalek) (Fig. 3). After 20 minutes, the wax form was removed from the mold, sprued, invested, and cast into 16 metal dies, then the dies were sandblasted by 50 µm aluminum oxide under three bar air pressure. The metal pellet of metal die was acting as mean of retention while the metal die inside the testing model. Each CAD/CAM crown was adhesively luted with Panavia F resin cement system (Kuraray, Osaka, Japan) and cemented to the metal die as follows: The inner surface of the crown was etched with hydrofluoric acid (IPS Ceramic etching-gel,Ivoclar Vivadent, Schaan, Liechtenstein) for 60 seconds, rinsed thoroughly with water, and air-dried. The surface was silanized with Monobond-S (Ivoclar Vivadent). Sufficient amount of Panavia F, paste A and paste B were dispensed on the mixing plate and mixed for 20 seconds. Then a thin layer of the resin was applied to the inner surface of the crown. The crown was seated to the metal die with finger pressure and then kept under a pressure of 40 N in a loading apparatus. The excess of the paste at the margin was removed and the margin area was cleaned with sponges. The air blocking gel Oxyguard II (Kuraray, Osaka, Japan) was syringed along the crown margin to prevent an oxygen inhibited unpolymerized resin layer formation and to enhance the chemical curing of the Panavia F. The cement was left for 7 minutes to set, and then the Oxyguard II was removed with a sponge and rinsed with tap water. The cementation procedures of all ceramic crowns to the metal dies were made according to manufacturer’s instructions.

The abutment of the testing model was surveyed to ensure that there were adequate undercuts (0.25 mm) (Tannous et al. 2012). Minor tooth preparation was performed to provide rest seat (the rest seat for E-clasp was prepared distally, however the rest seat for back action clasp was prepared mesially according to Pezzoli et al. 1993), this rest seat was triangular in shape, with the base of triangular was rested on marginal ridge and the rounded apex was directed toward the center of the tooth. The width of rest seat was one-half of the distance between the buccal and lingual cusp tips. The floor of it was spoon shaped and directed towards the center (Phoenix et al. 2003, Rice et al. 2011, Pospiech et al. 2012). Rest seat preparation was designed so that the occlusal forces were directed along the along axis of the tooth (Seals and Schwartz 1985). The palatal surface was re-contoured by using stone with low speed hand piece for lowering the height of contour to provide ideal balance (reciprocation) between two arms of the clasp; this balance was achieved when both arms contacted the tooth surfaces simultaneously so that stress exerted by the retentive arm was reciprocated by the bracing arm. A hand piece was attached directly to vertical spindle of dental surveying machine (F2, Degussa, Germany). Then a small piece of wax (0.7 mm in thickness, 20 mm in length, and 5 mm in width) having a small perforation at the its distal end, was fixed at the superior surface of the testing model, and 2 mm from the proximal tooth surface to provide framework stopper. The unwanted proximal undercuts were blocked out by using softened wax to eliminate its effect on the retention force (Soo and Leung 1996) and then trimmed by means of the wax trimmer of dental surveyor (Unit, Degussa, Germany) (Fig. 4).

Fig. 3. Duplicated mold was poured by melting speedy wax.

Fig. 4. The unwanted undercut was blocked out, and small piece of wax having hole at its distal end was fixed at the superior surface of the testing model.

The testing models were duplicated into investment models (Optivest, Degussa Dental, Hanau, Germany). Each group of the models was subdivided into two subgroups according to the framework design, subgroup E (SGE) for E-clasps and subgroup B (SGB) for back action clasps (8 specimens each). Each circlet (E) clasp consisted of a occlusal rest, two clasp arms (retentive clasp arm engaging a mesiobuccal undercut and a reciprocal lingual arm), and a minor connector that attached the clasp to the framework. In contrast, each back action clasp consisted of a occlusal rest, a single arm clasp which encircled nearly the entire circumference of the abutment, and a minor connector that attached the clasp to the framework. The bracing portion of the single clasp arm extended above the survey line on the lingual surface until the proximal surface, then it started its taper to become flexible and engage a mesiobuccal undercut (Krol et al. 1999, Phoenix et al. 2003, Carr et al. 2005).

On the investment models, the wax patterns of the frameworks were fabricated and finished, after that a small rectangular plastic piece (20 mm in length, 3 mm in height, and 5 mm in width) was fixed on the superior surface of the investment cast with 2 mm away from the distal surface of the abutment, by using softened wax. This rectangular plastic piece was placed parallel to superior surface of the investment cast. It was connected with the wax pattern of the clasp by wax. A small cylindrical plastic piece (20 mm in length and 5 mm in diameter) was placed manually inside the holding part of the testing column holder of the DRHD. Then it was held by tightening the screw of the holding part of the testing column holder of the DRHD. Then the investment cast was placed inside the specimen holder of the DRHD. The cylindrical plastic piece was fixed at 90 degree to the rectangular plastic piece by fast setting resin (Cyanacrylate, Renfert, Germany) to produce a testing column of the framework (Figs. 5-7).

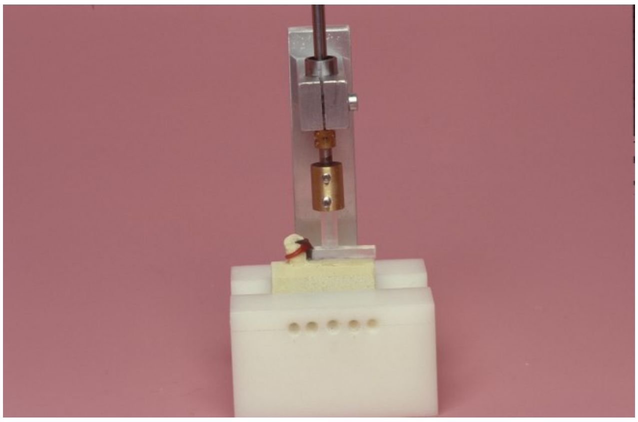

Fig. 5. Using DRHD for fixation of cylindrical plastic piece.

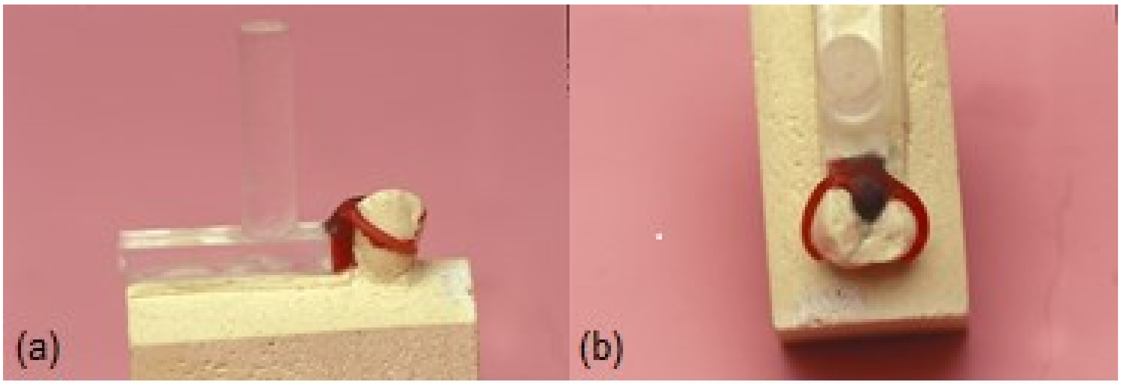

Fig. 6. Wax pattern of circlet (E) clasp: a, lateral view, and b, frontal view.

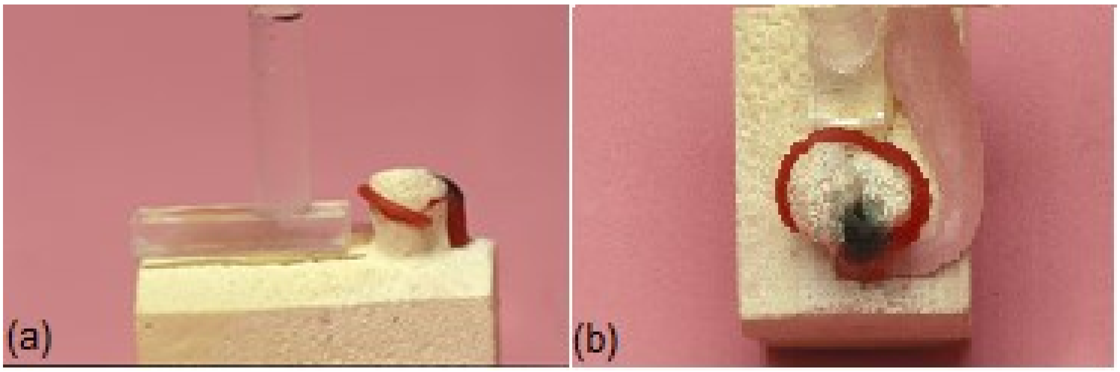

Fig. 7. Wax pattern of circlet back action clasp: a, lateral view, and b, frontal view.

Cast cobalt chromium alloy (BEGO, Bremen, Germany) frameworks with E-circlet and back action clasps were constructed (Bates 1965). The frameworks were tried on the models and were considered to be suitable for testing when the occlusal rests fit well in their rest seats, and the retainers were in contact with the abutments however the framework stopper was resting on the testing model (Figs. 8 and 9). The contact surface of each retainer and the edges of the clasps were examined visually to assure that they were free from pits and other irregularities that would affect retainer or material wear (Latta et al. 1997). The inner surface of the clasp tip was polished slightly using a rubber wheel at low speed to remove roughness and small projections on the fitting surfaces (Soo and Leung 1996).

Two saucer depressions as reference points were made at suspected wear area of abutment retention surface by gentle grinding using small round bur (Hebel et al. 1984, Davenport et al. 1988). They were placed one gingival to the suspected wear area below the clasp and the other one was above the height of contour.

Each clasp and its model were mounted on a DRHD and the whole test set-up was placed in a universal testing machine (Zwick/101, GmbH & Co. Germany). Retention of each clasp at pre-test (0 cycle) was measured by applying withdrawal force to it by this machine (Fig. 10).

Each subgroup of models (8 models) within the DRHDs were mounted inside a chewing simulator device (Firma Willytec, Munich, Germany) (Fig. 11). Removal and insertion cycling of clasps was carried out for 250, 500, 1,000, 2,000, 4,000, 8,000, and 16, 000 cycles. Specimens were cycled at room temperature in 200 ml artificial saliva (Hebel et al. 1984, Soo and Leung 1996) (Table 1). The machine was set at 8 mm/sec with 3 kg for loading.

Table 1. Composition of artificial saliva

Whole resting saliva (mg/100ml)		Supplied as
Na^+	15	38.1 mg NaCl/100 ml
K^+	80	88.2 mg KCl/100 ml
$(PO_3)^{4-}$	51(16.8 p)	5.4 ml 100 m $MKPO_4$ PH7
Ca^{++}	5.8	16 mg $CaCl_2$/100 ml
Mucin	200	Procine-mucine 200mg/100 ml

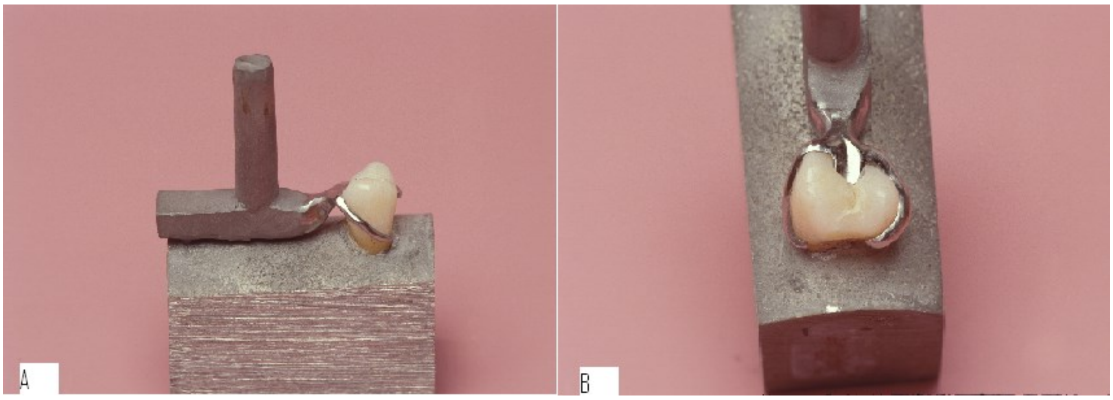

Fig. 8. Framework of E-clasp within the testing model, (A) lateral view and (B) frontal view.

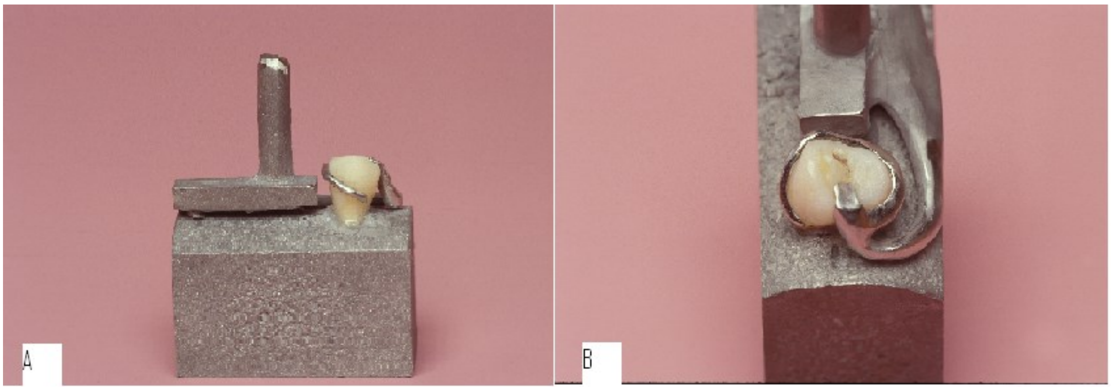

Fig. 9. Framework of Back action clasp within the testing model, (A) lateral view and (B) frontal view.

Fig. 10. The specimen (clasp within DRHD) was mounted in the universal testing machine.

Fig. 11. Clasps within DRHDs were mounted in the chewing simulator device.

After each cycling interval (250, 500, 1,000, 2,000, 4,000, 8,000, and 16,000 cycles) each clasp within the DRHD was removed from the chewing simulator device, and mounted in the universal testing machine, then the retention force was measured and after 16,000 cycles the loss of retention was calculated.

Acrylic replicas were made for each abutment retention surface before and after cycling as following: Silicon duplicating material was mechanically mixed and applied inside a duplicating ring. The crown of the abutment tooth was immersed into the duplicating material and left for one hour then removed. An epoxy resin (Stycast 1266, Emerson & Cuming, Westerlo, Belgium Germany) was mixed according to the manufacturer's instructions and poured into the mold. The ring was placed in a vacuum machine (Degusint Vac, Degussa, Germany) for 20 minutes to remove any air bubbles in resin. The epoxy resin was left to polymerize at room temperature for at least 24 hours (Marshall et al. 1978, Suzuki and Leinfelder 1993, Wood et al. 1996).

The replicas were attached to an aluminum stub for the scanning electron microscope (SEM) and sputtered coated with gold (Balzers Union, Balzers, Liechtenstein, Germany) (Fig. 12). The replicas were examined at the suspected wear areas by using the SEM (XL 30 CP, Philips, Eindhoven, Netherlands) at a magnification of X50 using a 10 kV acceleration voltage (Hebel et al. 1984, Dixon et al. 1990, Dixon et al. 1992, Tietge et al. 1992a, Tietge et al. 1992b, Suzuki and Leinfelder 1993).

The wear areas of the abutment surfaces were measured by using transparent paper scale in mm² as following; The SEM photograph was printed larger than normal at 100X magnification to clarify the wear area. Then the transparent paper was placed over the SEM photograph to trace out the wear areas.

The results of the retention forces at different intervals, the reduction of retention forces after 16,000 cycles, and the wear areas of the retention surfaces of different subgroups were tabulated and subjected to statistical analysis using 1-way-ANOVA, 2-way-ANOVA, and Mann-Whitney tests.

Fig. 12. The replica was attached to an aluminum SEM stub and sputter-coated with gold.

3. Results

3.1. Retention forces

The means of retention forces of the circlet (E) clasp and back action clasp on different abutment materials (enamel, composite resin, and ceramic) before and after cycling intervals are shown in Fig. 13 and Table 2.

Statistically, 1-way-ANOVA showed no significant differences among the means of retention forces of different subgroups initially and after 250, 500, 4,000, 8,000, and 16,000 cycles at 95 % confidence level (P>0.05). However, there were significant differences among the means of retention force of different subgroups after 1,000 cycles and 2,000 cycles at 95 % confidence level (P≤0.05). The circlet (E) clasp showed a significant decrease in retention compared to the back action clasp.

Also 2-way-ANOVA was used to study the effect of different clasp designs and abutment retention material on the retention force initially and after each interval. There was a significant effect of different clasp designs on the amount of retention force but the difference was only present after 4,000 cycles at 95 % confidence level (P≤0.05). There was no significant effect of using different abutment materials on the amount of retention force at different intervals at 95 % confidence level (P>0.05).

Pair-wise comparison (Mann-Whitney test) between the six subgroups after 1,000 cycles (Table 3) showed significant differences between SGBI and SGBII, SGEII and SGBII, and SGBII and SGBIII (P≤0.05). However, after 2,000 cycles there were significant differences between SGBI and SGBII, SGEII and SGBII, SGBII and SGBIII, and SGEIII and SGBIII (P≤0.05) (Table 4).

Table 2. Means and standard deviations of clasp retention (N) for subgroups at different cycle intervals

C	**SGEI**	**SGBI**	**SGEII**	**SGBII**	**SGEIII**	**SGBIII**
0	13.0±4	11.1±4.3	13.2±4.7	11.4±3.5	11.2±2.2	10.7±3.9
250	8.5±2.4	7.7 ±2	7.5±1.7	9.0±3.5	8.7±2	7.5±3.2
500	7.4±2.2	5.8±1.3	6.7± 1.5	8.8± 2.7	7.4± 2.7	7.7±1.8
1,000	7.7±3.3	5.9±0.7	5.1±1.8	8.6±1.4	5.5± 1.2	6.3±2.5
2,000	6.9±2.3	5.6±.9	5.1± 2.4	8.3±2.5	4.4±.8	6.0±1.2
4,000	5.7±1.8	5.3±.3	4.5±2.1	7.3±3.1	4.3±1.1	6.3±2.7
8,000	5.3±1.7	4.6±1.8	4.6±1.6	6.3±2	3.6± 1.3	5.0±3.2
16,000	3.34±1.7	4.6±2	4.2±1.6	5.0± 1.1	3.9± 1.4	4.4±4

C Number of Cycles, SD ± Standard Deviation, SGEI E-clasp on enamel, SGBI Back action clasp on enamel, SGEII E-clasp on composite resin, SGBII Back action clasp on composite resin, SGEIII E-clasp on ceramic, SGBIII Back action clasp on ceramic.

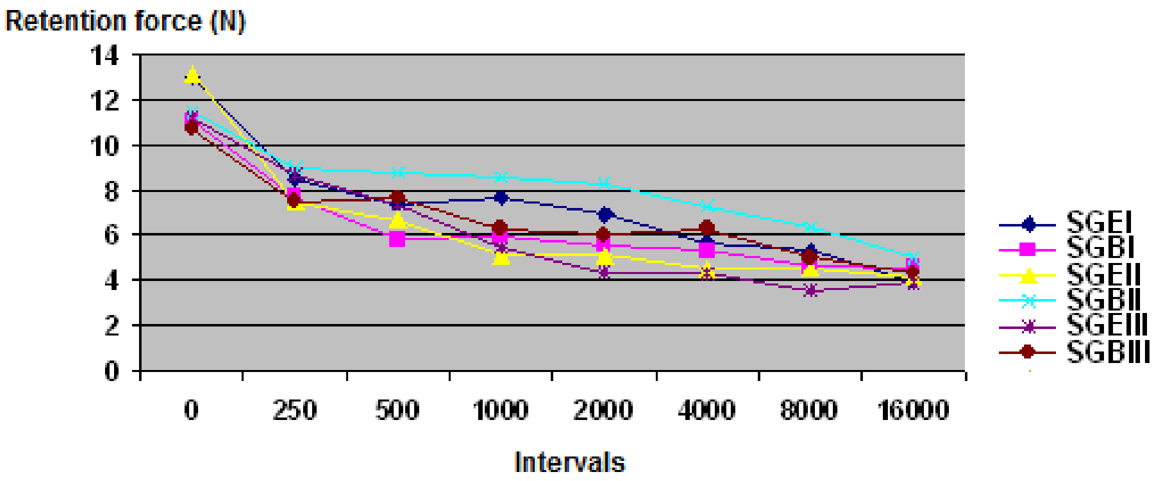

Fig. 13. Clasp retention of subgroups at different cycle intervals of attachment-detachment.

Table 3. Pair-wise comparisons of clasp retention between groups after 1,000 cycles (Mann-Whitney Test)

Groups compared			*P*
SGEI	Vs	SGEII	0.092
SGEI	Vs	SGEIII	0.092
SGEII	Vs	SGEIII	0.528
SGBI	Vs	SGBII	0.001*
SGBI	Vs	SGBIII	0.528
SGBII	Vs	SGBIII	0.040*
SGEI	Vs	SGBI	0.179
SGEII	Vs	SGBII	0.007*
SGEIII	Vs	SGBIII	0.291

Codes of subgroup see Table 2 on page 30,*denotes a significant difference ($p \leqslant 0.05$)

Table 4. Pair-wise comparisons of clasp retention between groups after 2,000 cycles (Mann-Whitney Test)

Groups compared			*P*
SGEI	Vs	SGEII	0.20
SGEI	Vs	SGEIII	0.08
SGEII	Vs	SGEIII	0.49
SGBI	Vs	SGBII	0.02*
SGBI	Vs	SGBIII	0.71
SGBII	Vs	SGBIII	0.03*
SGEI	Vs	SGBI	0.27
SGEII	Vs	SGBII	0.02*
SGEIII	Vs	SGBIII	0.01*

Codes of subgroup see Table 2 on page 30, *denotes a significant difference ($p \leqslant 0.05$).

3.2. Loss of retention force

Table 5 shows the mean and standard deviation of the loss of retention (N) after 16,000 cycles, and the percentages of retention loss of the E-circlet clasps and back-action clasps on different abutment materials (enamel, composite resin, and ceramic). Statistically, 1-wayANOVA showed no significant differences among the means of retention loss of different subgroups after 16,000 cycles at a 95% confidence level (*P*>0.05). Also, 2-way ANOVA was used to study the effect of different clasp designs or using different abutment retention surfaces on the amount of retention loss after 16,000 cycles. None of these factors had a statistically significant effect on loss of retention after 16,000 cycles at a 95% confidence level (*P*>0.05).

Table 5. Mean, standard deviation, and the percentages of loss of retention (N) after 16,000 cycles for each subgroup

SG	(No.)	Retention loss	Percentage of loss
SGEI	8	9.0 ± 4	69%
SGBI	8	6.3 ± 4.0	57%
SGEII	8	9.0 ± 3.8	68%
SGBII	8	6.0 ± 3.7	52%
SGEIII	8	7.0 ± 2.2	62%
SGBIII	8	6.3 ± 5.4	59%

Codes of subgroups see Table 2 on page 30, No. Number of specimens

3.3. Wear of abutment materials

Two-way ANOVA was used to study the effect of different clasp designs or using different abutment materials on the amount of wear. Both of these factors had a statistically significant effect on amount of wear at a 95% confidence level ($P \leq 0.05$) (Figs. 14-19) (Table 6). A pair-wise Mann-Whitney test showed significant differences between SGEI and SGBI, SGEI and SGEIII, SGBI and SGBIII, SGEII and SGEIII, SGBII and SGBIII, and SGEIII and SGBIII ($p \leq 0.05$); however, there were no significant differences between SGEI and SGEII, SGBI and SGBII, and SGEII and SGBII ($P > 0.05$) (Table 7).

Table 6. Mean and standard deviation of the wear areas of different subgroups after 16,000 cycles

Subgroup	No.	Mean ± SD
SGEI	8	1.83 ± 0.36
SGBI	8	0.85 ± 0.66
SGEII	8	2.37 ± 1.88
SGBII	8	1.70 ± 1.11
SGEIII	8	0.60 ± 0.20
SGBIII	8	0.06 ± 0.0

Codes of subgroups see Table 2 on page 30, No. Number of specimens

Table 7. Pair-wise comparisons of wear area between test subgroups after 16,000 cycles (Mann-Whitney test)

Groups compared			*P*
SGEI	Vs	SGEII	0.599
SGEI	Vs	SGEIII	0.0009*
SGEII	Vs	SGEIII	0.018*
SGBI	Vs	SGBII	0.172
SGBI	Vs	SGBIII	0.005*
SGBII	Vs	SGBIII	0.0005*
SGEI	Vs	SGBI	0.007*
SGEII	Vs	SGBII	0.372
SGEIII	Vs	SGBIII	0.0014*

Codes of subgroups see Table 2 on page 30, * denotes there is significant difference ($p \leqslant 0.05$).

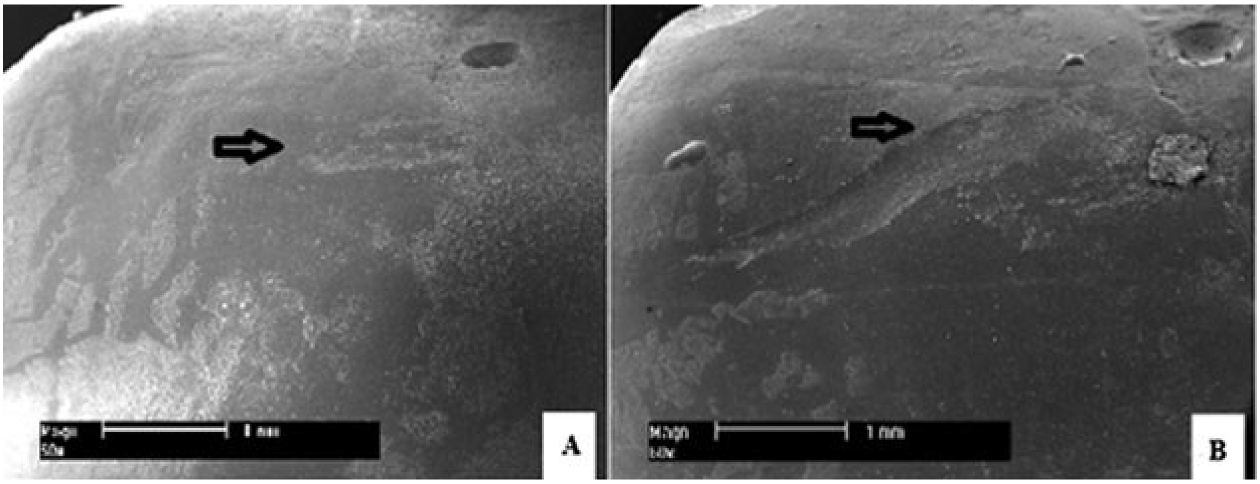

Fig. 14. Effect of E-circlet clasp on the enamel surface, (A) before cycling, (B) after cycling-

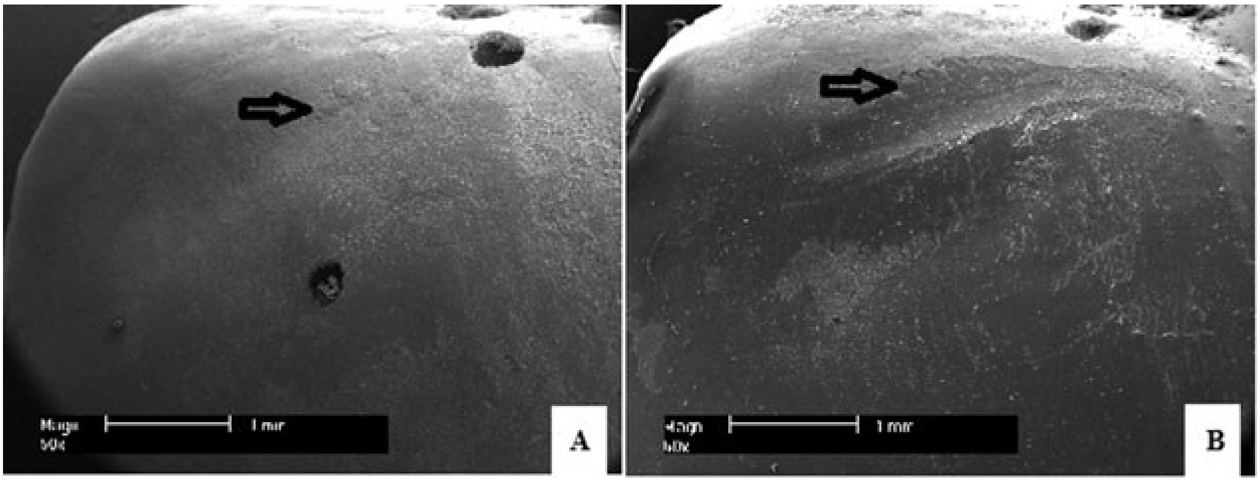

Fig. 15. Effect of a back-action clasp on the enamel surface, (A) before cycling, (B) after cycling.

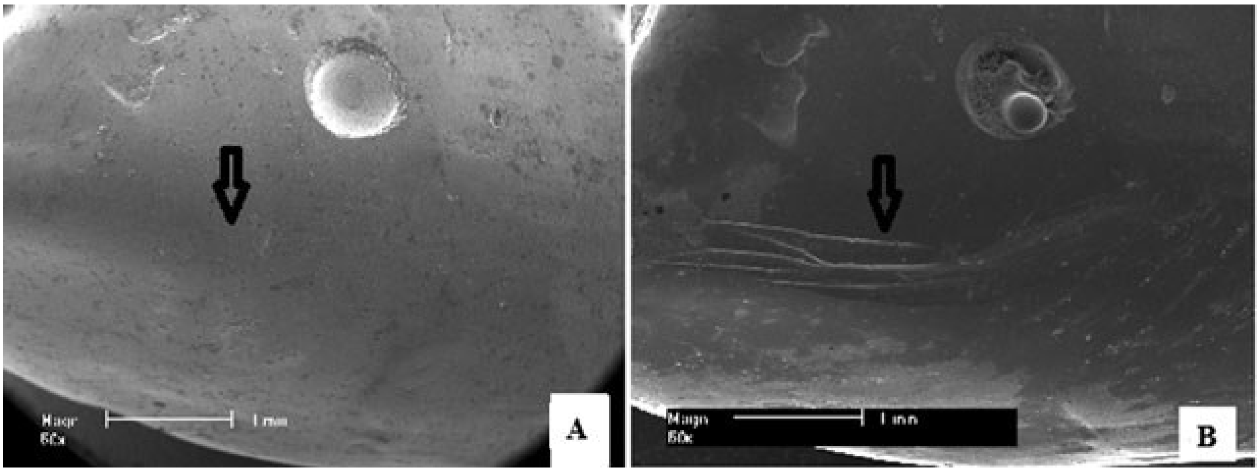

Fig. 16. Effect of an E-circlet clasp on the composite resin abutment material, (A) before cycling, (B) after cycling.

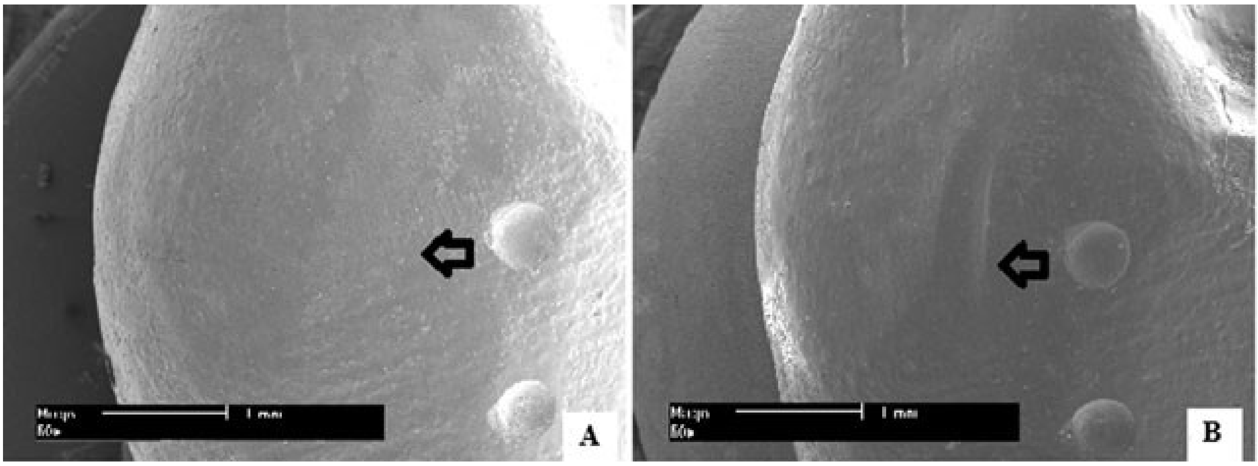

Fig. 17. Effect of a back-action clasp on the composite resin abutment material, (A) before cycling, (B) after cycling.

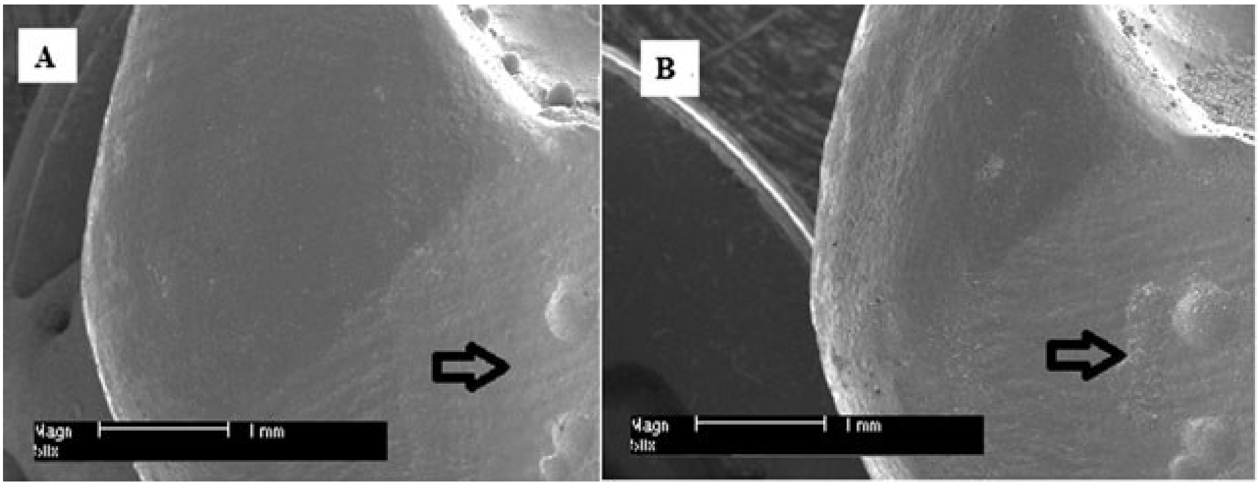

Fig. 18. Effect of E-circlet clasp on the ceramic abutment material, (A) before cycling, (B) after cycling.

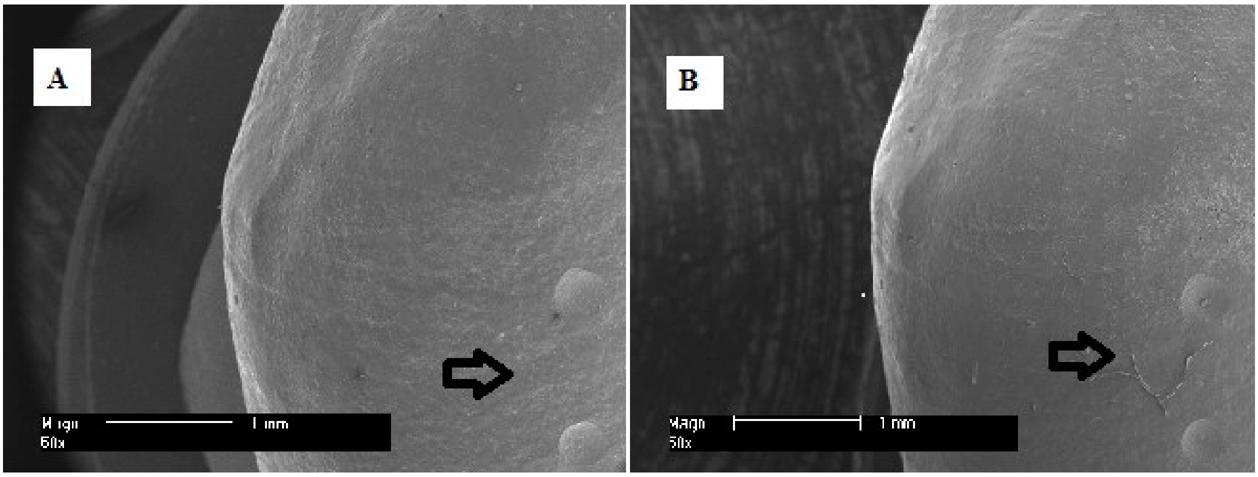

Fig. 19. Effect of back action clasp on the ceramic abutment material, (A) before cycling, (B) after cycling.

4. Discussion

4.1. Retention forces

All subgroups showed some degree of retention loss at different intervals, but the back action clasp significantly maintained its retention force for a longer period than the circlet (E) clasp. Therefore, the null hypothesis that there would be no difference in retention of circlet E-clasp and back action at different intervals was rejected.

Initially, no significant differences among the six subgroups were found ($p>0.05$). The mean retention in N was: 13 for SGEI, 11.1 for SGBI, 13.2 for SGEII, 11.4 for SGBII, 11.2 for SGEIII, and 10.7 for SGBIII. These results are in agreement with Firtell (1968), who found that the retention force of the E-clasp was about 13.7 N and for the back action clasp 1.6 N, and Bates (1963), who obtained similar results in a similar experiment. However the results of the currents study differ from a study done by Soo and Leung (1996), who reported that the retention force of Aker's clasp was 17.5 N.

The variation in retention force compared with the previous study may be due to the difference in the flexibility of the alloys used, or the amount of deflection, or the testing models.

The results of the current study shows that differences in clasp design have no effect on retention force initially and after 250, 500, 1,000, 2,000, 8,000, and 16,000 cycles ($P> 0.05$). An effect was only detected at 4,000 cycles ($P\leq0.05$).

Also there was significantly greater reduction of the retention of the circlet (E) clasps than of the back action clasps at 1,000 and 2,000 cycles ($P\leq0.05$), which might be caused by differences in flexibility between the two clasps. The back action clasp is more flexible than circlet (E) clasp because the back action clasp has a longer retentive arm (Osborne and Lammie 1953). Flexibility of the back action clasp allowed it to maintain its retention force up to 2,000 cycles, while the circlet (E) clasp deformed and lost its retention earlier (at 1,000 cycles). After 2,000 cycles, the back action clasps began to lose their elasticity and retention force. As a result there were no significant differences between the circlet (E) and back action clasps after 8,000 and 16,000 cycles ($P>0.05$), respectively.

In addition to the finding that the back action clasps maintained their retention force for a longer period than the circlet (E) clasps, the circlet (E) clasps exert lateral forces on the abutment teeth which may be detrimental to the periodontium and often fails because of distortion (Ahmed et al. 1992). Therefore the back action clasp seems preferable over the circlet (E) in terms of retention, longevity, and preservation of the abutment tooth supporting structures.

In the present study, there was significantly lower reduction in retention of the back action clasps on composite resin than on enamel and ceramic at 1,000 and 2,000 cycles ($P \leq 0.05$). However, at other cycle intervals there was no significant effect of the abutment materials on clasp retention ($P > 0.05$).

Early wear of the composite resin might have caused increase roughness on its surface and this might be responsible for an increase in the frictional force of the clasp arm with subsequent increase in retention. The retentive force of a clasp increases linearly with increasing friction coefficient between abutment material and clasp material (Sato 1997). These results are in accord with those of Jenkins and Berry (1976), Quinn (1981), Hebel et al. (1984), Davenport et al. (1990) and Davenport et al. (2001), and at variance with that of Dixon et al. (1990), Dixon et al. (1992), Tietge et al. (1992a), Tietge et al. (1992b). These findings suggest that composite resin contouring of teeth is viable technique for creating retention for the RPD clasps.

The validity of composite contouring the buccal retention surface of zero undercut teeth was confirmed by the absence of significant differences among the retention force of the back action clasp on the three retention surfaces at 4,000, 8,000, and 16,000 cycles. In addition, also there were no significant differences among the retention force of the circlet (E) clasp on the different abutment materials ($P > 0.05$).

The absence of significant differences between the retention of the back action clasp and circlet (E) clasp on the three retention surfaces at most of the intervals may be due to deformity of the two clasps at these cycling intervals. So the results of the present study suggest that the clasp may lose its retention force as a result of multiple deflections, which leads to gradual loss of elasticity.

4.2. Loss of retention force

The loss of retention of each clasp was choosing for comparison because it gives the results in numbers which are considered better suitable for comparison of subgroups rather than the percentages of loss. However the percentages of retention loss might be misleading reading but it can be used as indicator for the clinical acceptability.

There were no significant differences in the retention loss of all subgroups after 16,000 cycles at 95 % confidence level ($P>0.05$). However there were significant differences among the wear areas of abutment surface of the six subgroups after cycling at 95 % confidence level ($P\leq0.05$), which may reflect the effect of abutment retention surface on retention loss of RPD clasp after 16,000 cycles.

4.3. Wear of abutment materials

The wear of enamel by action RPD clasp was considered as a reference for this study, as Phillips and Leonard (1956) found no or little wear of enamel by action of the direct retainer. Although wear was measured only two-dimensional it can be assumed that the measured 2-D wear facets correlate strongly with the three-dimensional wear (volume) as the tooth curvature approximates the shape of a cup (dome). Under this consideration the calculation of the volume loss would be as follows: $V_{cup} \approx \frac{S^2}{3*C}$

V_{cup}= volume of the cup removed by wear (cup over the measured area), S = measured (worn) area, C= circumference of the tooth at the equatorial cross-section (i.e. circumference of the embrace).

As the tooth shape approximates only the shape of a cup (dome) volume loss could not be calculated but it is reasonable to assume that the measured 2-D wear correlates strongly with the 3-D wear on the curved tooth surface.

There were significant differences among the different retention surfaces by the action of the two clasps ($P\leq0.05$). Therefore, the null hypothesis that there would be no difference in wear of retention surfaces by the effect of circlet E-clasp and back action clasp at different intervals was rejected.

The results of this in vitro experiment indicated that the RPD clasps had a wearing effect on the enamel surface of the abutment teeth. Over an 11 years period of simulated insertion and removal cycles, the wear area was 1.83 mm^2 for SGEI and was 0.85 mm^2 for SGBI. These results are varying from that of Phillips and Leonard (1956) and Hebel et al. (1984). Differences in methodology, amount of undercut, clasp designs, the dislodgement force, number of cycling, and increased sophistication of equipment used to measure wear, may be responsible for the differences in wear recorded by the different studies.

The composite resin contoured teeth showed significantly higher wear than the enamel by the action of E and back action clasps which may not clinically accepted . These finding were in agreement with Hebel et al. (1984), Davenport et al. (1988), and Tiegte et al. (1992) and at variance with Swift (1987).

No significant changes were found in the ceramic abutment retention surface by the action of E and back action clasps. None of the specimens failed due to ceramic fracture, which indicates that well fabricated glazed ceramic surface can withstand the wear forces of RPD retentive clasp arms. These results are in agreement with that of Marso et al. (1981) and Tiegte et al. (1992b).

Statistically there were significant differences in the wear of enamel and ceramic abutment retention surface by the action of E and back action clasps ($P \leq 0.05$). These significant differences may be due to the rigidity of the E-clasp which is higher than that of back action clasp.

There were significant differences among the different retention surfaces by the action of the two clasps. Ceramic showed the least amount of wear followed by enamel and then by composite which showed the largest amount of wear. This is probably due to the differences in wearing resistance of these materials.

All specimens exhibited some retention at the end of this study (after 16,000 cycles) and there were no significant differences in the retention loss of all subgroups at 95 % confidence level ($P > 0.05$) after 16,000 cycles. However, no resin additions were lost during the course of the experiment and none of the specimens failed due to composite fracture. In spite of the fact that direct retainers cause wear of composite resins, these materials have been recommended for creation of abutment tooth undercuts, this also suggests that resin contouring of teeth is viable technique for creating retention for the RPDs clasps. This finding was in agreement with Hebel et al. (1984), Davenport et al. (1988), and Pavarina et al. (2002). In addition it should be mentioned, that worn composite resin could be easily replaced by newly added composite resin while worn ceramic cannot be replaced easily.

5.1. Summary

The purpose of this in-vitro study was to compare the retention of circlet (E) clasps and back action clasps against three different abutment surface materials (enamel, composite, CAD/CAM ceramic crown) during long-term simulation of attachment and detachment, and to measure the loss of retention and wear after 16,000 simulated cycles of attachment-detachment. Forty-eight models were constructed by placing either an upper first premolar or a metal die inside a metal rectangular block. Models were divided according to the abutment teeth into three groups. Group GI consisted of 16 unrestored human premolars with sound enamel. Group GII had 16 premolars re-contoured buccally using composite resin. Group GIII had 16 metal dies (duplicated from a human premolar) covered by CAD/CAM all-ceramic crowns. On the models, E-circlet (E) and back-action (B) clasps were constructed to engage the model's teeth. Removal and insertion cycling of clasps was carried out for 250, 500, 1,000, 2,000, 4,000, 8,000, and 16,000 cycles by using a chewing simulator. The retention force of each clasp was measured before cycling and at different intervals by using universal testing machine. An acrylic replica was made for each abutment retention surface before and after cycling. Each replica was examined by SEM, and the wear areas were measured. The data was analyzed statistically using 1-way ANOVA, 2-way ANOVA, and Mann-Whitney tests.

No significant differences in retention of either clasp were found between the three abutment material surfaces. However, there was a significant decrease in retention force of the circlet (E) clasp between 1,000 and 2,000 cycles but not the back action clasp. There were no significant differences in retention loss after 16,000 cycles ($P \geq 0.05$) of both clasps (E, B) on the three abutment materials (enamel, composite resin, CAD/CAM ceramic crown). There were significant differences among the wear areas of the abutment surface of the six subgroups ($P \leq 0.05$). Within the limitations of this study, the following conclusions were drawn: 1) The back action clasp maintains its retention force for a longer period than the circlet (E) clasp. 2) Composite resin contouring of teeth seems to be a viable technique for creating retention for the RPD clasps because there was no significant difference between the 3 abutment materials regarding their retention forces at different intervals ($P > 0.05$). 3) The difference in design between circlet E-clasps and back action clasps had no significant effect on the loss of retention force

after 16,000 cycles. 4) Using different abutment surfaces for clasp retention had no significant effect on the amount of retention loss after 16,000 cycles. 5) The composite resin contoured teeth showed more wear than the enamel and ceramic by the action of E and back action clasps. However, E-clasps caused more wear on the abutment materials than back action clasps.

5.2. Zusammenfassung

Das Ziel dieser In-vitro-Studie war es, die Retention von E-Klammern und Back-Aktion-Klammern auf auf drei Materialien zu vergleichen (Schmelz, Komposit, CAD/CAM-Keramik-Krone) und messen den Verlust der Retention und die Abnutzung der Retentionsflächen bei langfristiger Simulation von Fügen und Lösen der Klammern nach bis zu 16.000 Zyklen zu evaluieren. 48 Modelle wurden hergestellt, indem entweder ein natürlicher oberer erster Prämolar oder ein Metallpfeilerzahn in einem rechteckigen Metallblock eingebettet wurden. Die Modelle wurden entsprechend Ihrer Pfeilerzähne in drei Gruppen eingeteilt. Gruppe GI bestand aus 16 nicht restaurierten menschlichen Prämolaren mit gesundem Zahnschmelz. Gruppe GII beinhaltete 16 Prämolaren, die bukkal mit Komposit rekonturiert worden waren. Gruppe GIII wies 16 Metallstümpfe auf (dupliziert von einem präparierten menschlichen Prämolaren) die mit CAD/CAM-Vollkeramik-Kronen versorgt wurdent. Auf den Modellen, wurden die beiden Klammern (E) und (B=Back-Aktion) so konstruiert, das sie die Zähne zirkulär umfassten. Das Fügen und Lösen der Klammern wurde für 250, 500, 1.000, 2.000, 4.000, 8.000, und 16.000 Zyklen unter Verwendung eines Kausimulator durchgeführt. Die Retention der einzelnen Klammer wurde vor Beginn der Füge- und Lösezyklen und dann in unterschiedlichen Abständen mit Hilfe einer Universal-Prüfmaschine gemessen. Ein Acryl-Replika wurde für jede Material-Oberfläche vor und nach dem den Füge- und Lösezyklen hergestellt. Jedes Replika wurde im Rasterelektronenmikroskop untersucht und der Verschleiß an der Anlagefläche der Klammern gemessen. Die Daten wurden unter Verwendung von ein- oder zweifaktorieller Varianzanalyses und Mann-Whitney-Tests statistisch ausgewertet.

Es wurden keine signifikanten Unterschiede in der Retention der Klammertypen oder in Abhängigkeit von den Materialoberflächen gefunden. Allerdings gab es eine signifikante Abnahme der Klammerretention zwischen 1.000 und 2.000 Zyklen bei den der E-Klammern, nicht aber bei den Back-Aktion-Klammern. Es gab keine signifikanten Unterschiede im Retentionsverlust der beiden Klammertypen nach 16.000 Zyklen ($P \geqslant 0{,}05$) welcher auch nicht vom verwendeten Material (Schmelz, Komposit, CAD/CAM-Keramik-Krone) beeinflusst wurde. Es wurden aber signifikante Unterschiede bezüglich des Verschleißes der Retentionsflächen der sechs Untergruppen festgestellt ($P \leq 0{,}05$). Unter Berücksichtigung der Studienlimitationen können folgende Schlussfolgerungen gezogen werden: 1) Die Back-Action-Klammer behält ihre Retentionskraft für einen längeren Zeitraum als die E-Klammer. 2) Die Konturierung der Zähne mit Kompositkunststoff scheint eine praktikable Technik zur Schaffung von Retentionflächen für Gussklammern dazustellen, da es keine signifikanten Unterschiede zwischen den 3 Materialien in der Klammerretention in den unterschiedlichen Intervallen gab ($P>0,05$). 3) Der Unterschied im Design zwischen E-Klammern und Back-Aktion-Klammern hatte keinen signifikanten Einfluss auf den Verlust der Haltekraft nach 16.000 Zyklen. 4) Die verschiedenen Anlageflächen der Klammern hatte keinen signifikanten Einfluss auf die Höhe der Retention Verlust nach 16.000 Zyklen. 5) Die mit Kompositkunststoff rekonturierten Zähne wiesen einen höheren Verschleiß auf als die Zähne mit nicht restaurierten Schmelz und die Keramikkronen. Allerdings verursachten die E-Klammern mehr Verschleiß an den Materialien als die Back-Aktion-Klammern.

6. References

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