Assessment of retention characteristics of different attachments following new modifications (an in vitro study)

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Background and objectives: This study aimed to compare the retention characteristics of different attachments used to retain partial dentures following new modifications.
Methods: In this study three types of commonly used extracoronal castable attachments were selected, namely (1) Preci-verttix standard, CEKA attachment, (2) Preci-sagix mini size, CEKA attachment, (3) OT- cap normal, Rhein 83. They underwent simple modifications in order to improve their retention. A total of forty-two samples were prepared in three main groups. Each group subdivided into two subgroups with fourteen samples; 7 samples for non-modified and 7 for modified attachments. The tensile force was applied using a universal testing machine at a cross-head speed of 50 mm/min and maximum retention force at dislodgment was recorded. Strain and stress at dislodgement were calculated. Data were collected and analyzed using one- way ANOVA followed by Duncan test and finally paired t-test was performed for comparing the modified and non-modified attachments.
Results: For all attachments, retention was increased significantly following modification except for OT-cap, which showed a non-significant reduction in retention. Modified Preci-vertix attachment was most retentive with the mean value of (48.893) Newton. For all attachments strain at dislodgement was increased after modification and highest mean value of (1.292) was recorded for Preci-sagix. Stress at dislodgement was increased following modification for all attachments, except Preci- vertix which showed significant reduction of stress.
Conclusions: Modified Preci-vertix attachment showed the highest retention value with a significant reduction in stress.
Keywords: Retention, Attachment, Stress, Strain

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Introduction

A unique concern of a removable denture when compared to others is retention.[1,2] Retention is the ability of the dental prosthesis acting to prevent its displacement along the path of insertion.[1,3] Retention is an important factor in the removable partial dentures design also there is a strong indication that retention plays an important role in a patient's satisfaction.[4,5] Distal extension bases show a composite type of support gained from both the teeth and residual ridges.[6–8] They are predisposed to forces tending to cause movement of the denture base under functional loading resulting in the destruction of the supporting structures and patient discomfort. These forces should thus be appropriately controlled, reduced and directed by biomechanical denture planning.[7]

It is better to design a Removable Partial Denture (RPD) for partially edentulous arches in a systematic manner.[9]

Consideration must be given to retention, support, stability, comfort, and esthetics when designing an RPD. Precision attachments may be the treatment of choice to the problem of retainers for partially dentate cases. Clasp arm direct retainers placed on canine and premolar teeth may be esthetically unacceptable. Correct use of attachments may eliminate the need for facial clasp arms while providing acceptable retention, support, and stability to the prosthesis. As a result, both esthetic appearance and psychological acceptance of the prosthesis will elevate [7,10,11]

Extracoronal attachment direct retainers are mechanical devices that are located entirely outside the clinical crown of the teeth. They provide a rigid, or flexible connection between abutment teeth and an RPD. Extracoronal attachment is a sliding joint that obtains its retentive features from closely fitting parts. Many attachments showed some kind of flexibility under the occlusal forces. This can reduce the transfer of destructive forces to the abutments and residual ridges. This concept supports the "stress-breaking" philosophy of the RPD design.[7]
When analyzing the resistance to dislodgment (retention) of the RPD there are two sides of retention: first, the perception of the patient, i.e., the feeling of how secure the prosthesis is in place as the denture is removed and separated from the abutments (break load or breakaway force); and second the perspective of the clinician, i.e., the measurement of the peak load (maximum dislodging force) as the denture is resisting removal from the patient's abutments.[12] This experiment studied this second aspect of retention, as it compared the maximum dislodging force of the different attachments following simple modification. Consequently, the aim of this study was to assess the effects of new modifications in the attachments on the amount of retention provided by them and compare the retention characteristic of the attachments before and after such modifications.

Methods

Three types of extracoronal castable attachments were used. They were: (1) Preci-vertix (PV) standard, CEKA attachment, (2) Preci-sagix (PS) mini size, CEKA attachment, (3) OT- cap (OT) normal, Rhein 83, as shown in the Figure 1. All modifications were done through increasing the retention of the attachments and reducing the stress on the abutments and the residual ridges.

Modifications of Attachments

The PV attachment is composed of two parts; PV plastic female part which is placed within the RPD, and PV plastic male part which is cast in hard dental alloy and attached to the crown of the abutment tooth. Modification was done only for the male part. Normally the male part is casted parallel to the long axis of the abutment tooth and is vertically oriented. In modified attachment the male part was processed in a way that it was placed parallel to the residual ridge and was horizontally oriented as shown in Figure 2. This modification was done in order to increase the retention through increasing the surface areas of the attachment.

The PS attachment is composed of two parts; PS female part which is yellow in col-

Figure 1. Attachments used in this study: A. Preci-vertix (PV), B. Preci-sagix (PS), C. OT-cap (OT)

or and is fixed inside the RPD, and spherical plastic male part which is cast in hard dental alloy and attached to the crown of the abutment tooth as seen in the Figure 1. The OT-cap attachment is composed of two parts; the retentive cap or female part which is fixed inside the RPD, and spherical plastic male part which is cast in hard dental alloy and attached to the crown of the abutment tooth. Retentive cap is available in different colors with different elasticity. The spherical male part also comes in two sizes; micro size which is red in color and the normal size which is green in color. In this study normal size pink retentive cap and normal size green color spherical male were used (Figure 1).

Same modifications were done for the male parts for both PS and OT attachments. A round disk with 0.4 mm thickness was used to prepare a slot in the spherical plastic male part. The slot was created in the center of the spherical male part after it was casted into Co-Cr dental alloy. For standardization, after finishing, the sample containing the male part fixed on base to prevent its movement, and the center of the sphere was marked with indelible pen. The disk was placed into the engine and slot was created in the center of the spherical Co-Cr male part Figure 2. For both attachments, the modifications were performed only in the male parts and it is not affect the design of the corresponding female parts.

Sample Preparation

For performing the retention test Universal Testing Machine (UTM), (Gunt WP-500, Germany) was used. The samples were prepared in such a manner that it was fixed on the UTM without movement. For this purpose a special cubic square metal holder with dimensions of 4 cm was made with a threaded hole with diameter of 1.5 cm in its center. The holder was fixed to the UTM with screw through the threaded hole. The upper part of the holder was shaped like a room that hold the samples in place during testing procedure as seen in Figure 2.

A wax block was prepared and shaped in a manner that it was fully seated within the room of the metal holder. Then the plastic male (patrix) parts of all the attachments were fixed to the center of the wax block. Another wax block was prepared to hold the plastic female (matrix) part. Its upper part was shaped like a ring and the lower part was shaped to make a room for the matrix of the attachment. The lower part of the wax block should be designed according to the shape of each matrices in a manner that each matrix fitted with in the prepared room in the wax. The Figure 3 and 4 demonstrated the steps for preparation of different samples. The ring was made to be grasped by a metal hook. The hook was connected to the upper part of UTM. This waxing procedure was followed for preparation of all samples. Then all steps were followed to convert the wax samples with plastic male part into the hard cobalt chromium alloy as seen in Figure 3 and 4. The wax blocks holding the male and female part of the attachment either completely processed in to Co-Cr alloy in case of Preci-vertix and Preci-sagix or acrylic resin in case of OT-cap attachment as seen in Figure 2, 3, and 4. For each test group seven samples were prepared. After processing of the wax the plastic female part was fixed into its position and if needed it was fixed by using glue. This procedure was followed for preparation of all samples.

Testing Procedure

The metal holder was fixed to the lower compartment of the UTM with screw. Each

Figure 2. A. Modified and non-modified Preci-vertix and B. modified Preci-sagix samples. C. modified OT-cap sample D. special metal holder with the threaded hole in the center and a room for the samples.

prepared sample was fitted into the room provided within the metal holder. A metal hook with two head was used, one head entered the ring of the sample and the other head was connected to the upper compartment of the UTM and was fixed with screw. During the test procedure the metal hook was pulling the female part of the attachment until it was completely separated from the male part as seen in Figure 5. For each experimental attachment tensile force was applied by the UTM at a cross-head speed of 50 mm/min. This cross-head speed has been reported in the literatures to approximate the clinically relevant movement of the denture away from the residual ridge.[13–16] The force was applied manually until the two parts of the attachment were separated, and at the time they were separated the retention force or maximum dislodging force[17] was recorded by the computer attached to the UTM. The Instron UTM was connected to the computer. The software program (Wp 300_20) was used which recorded the forces in Newton and automatically calculated the stress, strain and stress-strain curve. For each sample, five readings were recorded and the mean for each sample was calculated. A period of five minutes between each readings was considered as a period of rest which helped the recovery of female plastic parts of the attachments.

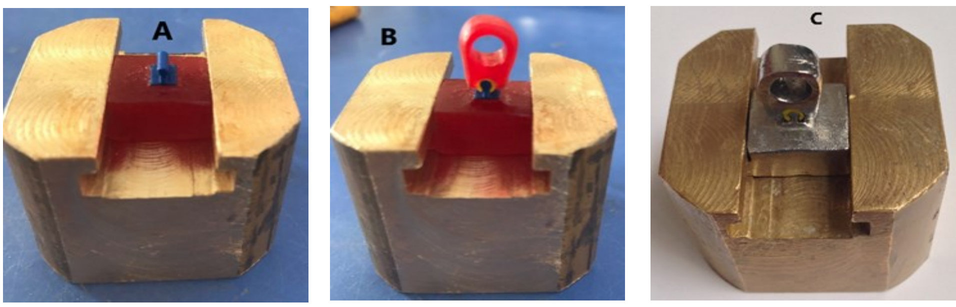

Figure 3: A. The plastic male part of Preci-vertix (PV) fixed into wax block and accommodated into the metal holder, B. the holder with both part of PV attachment fixed in wax and fitted into metal holder. C. prepared modified sample of PV attachment after it was processed into Co-Cr alloy.

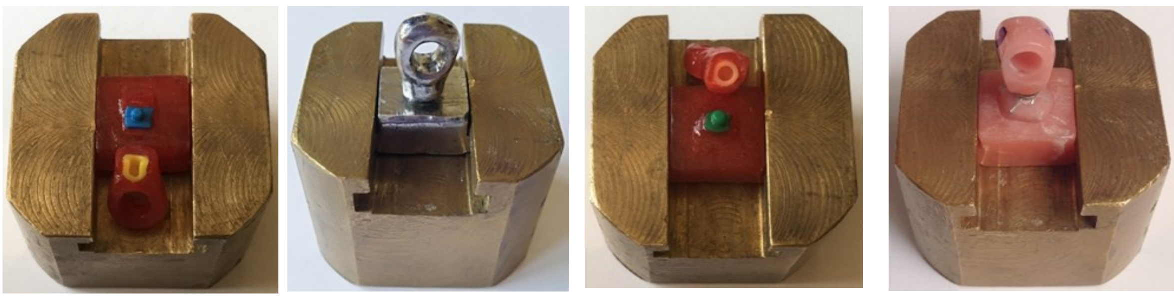

Figure 4. A. Both patrix and matrix of Preci- sagix (PS) attachment fixed into wax block. B. Prepared PS sample fitted into the metal holder. C. Both patrix and matrix of OT-cap attachment fixed into wax block. D. Prepared OT-cap sample fitted into the metal holder.

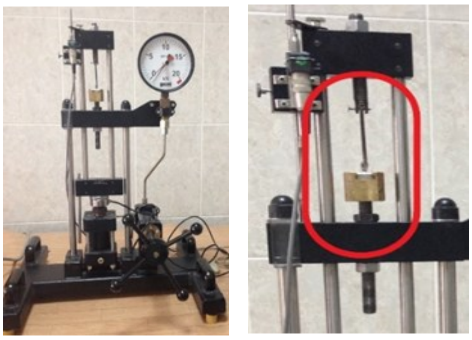

Figure 5. A and B. Universal testing machine with sample fixed for retention test.

Once the two parts of the attachment separated, the force was recorded in Newton (N), and it was the maximum retentive force of each attachment. Stress (σ) is obtained by dividing the force by surface area of the attachment. Strain (Є) was calculated by dividing the change in length (the distance that matrix part of attachment moved, till it is completely separated from the patrix part) by the original length of the attachment. Stress and strain were calculated using the following equations:

$$\sigma = \frac{F\ (N)}{A\ (mm^2)}$$ F / A

Where:

σ = Stress F = Force (N)

A= surface area in mm^2 $A=\pi r^2$

$$Є = \frac{dL\ (mm)}{L0\ (mm)}$$

Where:

Є = Strain dL=change in length

L0 = original length

Data Analysis

Statistical analysis was performed with the statistical package for social sciences (SPSS version 26). Before analysis, Shapiro-Wilk test was used to test the normality of the recorded data. The result indicated that the data was parametric and normally distributed. Therefore, One- way analysis of variance (ANOVA) was done for comparison between groups, followed by post hoc Duncan test for multiple range comparison between groups. Then paired t-test was used for comparing the attachments before and after modifications. If *P*-value is less than 0.01it means that statistically the result is highly significant (HS). When *P*-value is less than 0.05 and greater than 0.01, it indicates that the difference was significant (S) statistically. Finally, the result is not significant (NS) statistically, if *P*-value is greater than 0.05.

Results

The results with statistical analysis of one-way ANOVA and Duncan test was summarized and presented in Table 1 and 2.

Results of one- way ANOVA revealed that there was a highly significant difference between the groups of the study. Dislodgement force for all attachments ranged from 16.891 N to 48.893 N. Strain at dislodgement for all groups of the study ranged from 0.366 to 1.292. Stress at the time of dislodgement fluctuated from 3.787 N/ mm^2 to 23.369 N/ mm^2. The modified PV attachment demonstrated the greatest retention, with the peak force to dislodgement of 48.893 N and the lowest retention was recorded for modified OT of 16.891 N.$^{(a)}$ $^{(a)}$, $^{(b)}$ $^{(b)}$ and $^{(c)}$ $^{(c)}$ denotes that there is no significant difference between two means by Duncan multiple range test. But $^{(a)}$ $^{(b)}$, $^{(a)}$ $^{(c)}$ and $^{(b)}$ $^{(c)}$ denotes that there is significant difference between two means.
Paired t-test was used for comparing retentive force, strain and stress at dislodgement of each attachment before and after modification. The statistical results are displayed on Table 3. It is apparent that retentive force of PV attachment was increased dramatically after modification and statistically the result was highly significant. While retention of OT attachment relatively decreased after modification, but the result was not significant statistically.

For all groups of the attachments strain at dislodgement was increased after modification.

In case of PV and PS attachment, strain at dislodgement was about one and half time greater than before modification and statistically the result was highly significant. Whereas, modified OT displayed slight increase in strain, which was not significant statistically. As clearly observed, PS attachment revealed dramatic increase in stress which was statistically highly significant. At the same time stress at dislodgement of PV attachment deeply decreased following modification which was statistically highly significant.

Concerning the stress-strain curve we only put six curves. Because we had 42 samples and for each samples we did five reading, if we put the curves for all samples it will be too much, so we select six curves, one from each group. Figure 6 demonstrated the stress -strain curve for different groups of the study.

Table 1. Summery of one way ANOVA and Duncan test comparison for non-modified attachments

	Attachment (Non-modified)	No.	Mean (Duncan)	Standard Deviation	F-test One Way ANOVA	P-Value (Sig.)
Force (Newton)	Preci-Vertix	7	28.134[b] ¶	3.178	13.756	0.000 (HS)
	Preci-Sagix	7	21.469[a]	5.158		
	OT-cap	7	18.557[a]	0.303		
	Total	21	22.720	5.283		
Strain	Preci-Vertix	7	0.366[a]	0.150	14.644	0.000 (HS)
	Preci-Sagix	7	0.697[b]	0.132		
	OT-cap	7	0.639[b]	0.070		
	Total	21	0.568	0.188		
Stress (N/mm^2)	Preci-Vertix	7	8.654[b]	0.996	31.903	0.000 (HS)
	Preci-Sagix	7	9.334[b]	2.243		
	OT-cap	7	3.787[a]	0.062		
	Total	21	7.259	2.866		

Table 2. Summery of one way ANOVA and Duncan test comparison for modified attachments

	Attachment (Modified)	No.	Mean (Duncan)	Standard Deviation	F-test One Way ANOVA	P-Value (Sig.)
Force (Newton)	Preci-Vertix	7	48.893[c]	14.230	19.798	0.000 (HS)
	Preci-Sagix	7	30.449[b]	7.656		
	OT-cap	7	16.891[a]	3.544		
	Total	21	32.078	16.208		
Strain	Preci-Vertix	7	0.740[a]	0.135	13.092	0.000 (HS)
	Preci-Sagix	7	1.292[b]	0.346		
	OT-cap	7	0.682[a]	0.209		
	Total	21	0.905	0.366		
Stress (N/mm^2)	Preci-Vertix	7	4.613[a]	1.342	68.994	0.000 (HS)
	Preci-Sagix	7	23.569[b]	5.764		
	OT-cap	7	4.826[a]	1.013		
	Total	21	11.003	9.682		

Table 3. Summery of t-test for comparison of retention, strain and stress on dislodgement among different groups

	Attachment	Mean	Std. Deviation	t-test	df	*P*-value
Force (N)	Non-modified PV	28.1343	3.17825	-3.982	6	0.007 (HS)
	Modified PV	48.8929	14.23032			
	Non-modified PS	21.4686	5.15812	-2.459	6	0.049 (S)
	Modified PS	30.4486	7.65604			
	Non-modified OT	18.5571	0.30341	1.287	6	0.245 (NS)
	Modified OT	16.8914	3.54406			
Strain	Non-modified PV	0.3663	0.14979	-5.398	6	0.002 (HS)
	Modified PV	0.7405	0.13481			
	Non-modified PS	0.6973	0.13246	-4.139	6	0.006 (HS)
	Modified PS	1.2918	0.34572			
	Non-modified OT	0.6394	0.06954	-0.468	6	0.656 (NS)
	Modified OT	0.6821	0.20947			
Stress (N/mm2)	Non-modified PV	8.6545	0.99594	7.335	6	0.000 (HS)
	Modified PV	4.6125	1.34248			
	Non-modified PS	9.3342	2.24266	-5.938	6	0.001 (HS)
	Modified PS	23.5692	5.76420			
	Non-modified OT	3.7872	0.06192	-2.784	6	0.032 (S)
	Modified OT	4.8261	1.01259			

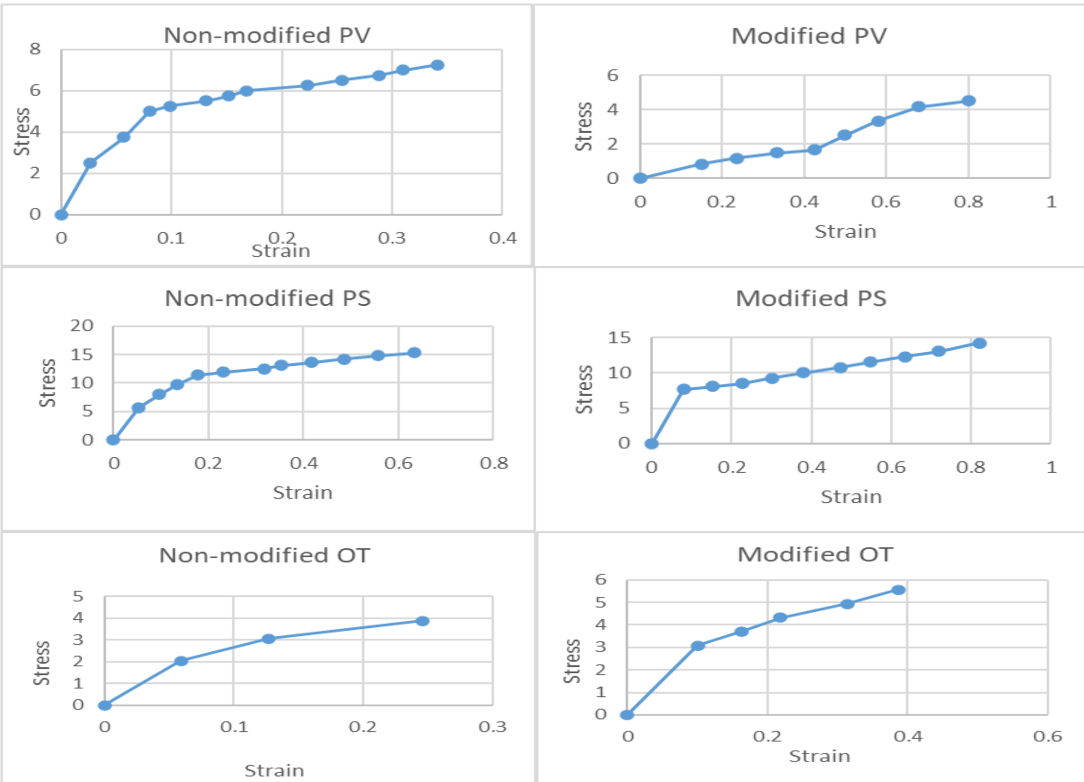

Figure 6. Stress-strain curves for different samples. PV (Preci-vertix), PS (Preci-sagix), OT (OT-Cap) attachments.

Discussion

The primary retention of a certain attachment system or design may direct its clinical predictability and performance and affect acceptance of the patient for the prosthesis.[18] The amount of retention that is clinically required has not been clearly established. In some sources it is point out that a mean load of 3 to 7.5 N is necessary for retaining a Class I Kennedy RPD.[4,19] Based upon previous studies, it can be established that an effective retentive force may be between 8 and 10 N. [2] No agreement exist over the optimal retentive force of a denture. That's while a former study suggests that a stud attachment should have a retentive force of at least 4 N, but manufacturers are providing a very limited amount of data about the retentive force of the attachment. Moreover, concerning the primary retentive force of the attachment system the literature consist of various opinions, even for similar types of attachment systems, based on the experimental conditions, such as the direction of application of force, crosshead speed, and the distance and angle of attachments.[20] It is known that attachments must have a retentive force of at least 5 N to retain prosthetics in place during function. However, daily use, the oral conditions, and parafunctional activities may affect the retentive capability of attachments. [21]

The result of this in vitro study showed that the retentive force of both PV and PS attachments were increased after modification. While for OT attachment, retention was reduced following modification. Increasing the retention of PV attachment may be due to increase in the surface area of the modified attachment. This agrees with the study done by Petropoulos and Smith in 2002, in which they measured the maximum retention force of different stud attachments. They found that the ZAAG (Zest Anchor Advanced Generation) is more retentive than ZA (Zest Anchor). The superior retention of the ZAAG over the ZA is the result of the increased surface area of the larger and wider retentive band. This is similar to a tooth preparation, in which longer preparations will have more surface area and the crown will be more retentive.[12] Also this study has similar findings with a study carried out by Botega and his coworkers in 2004. They investigated the retention force and fatigue strength of two overdenture attachment systems. They found that attachment with greater surface area revealed more retention compared with attachment with smaller surface areas.[22] Similarly Reda et al found that greater cross-section of the attachment increases surface area available for frictional contact between components of attachment and results in more retention.[15] Additionally, intimate contact between attachments parts could partially explain increase in retention.[4]

In this study, strain at dislodgement was increased for all modified attachments, and highest amount was recorded for PS attachment. Overall the strain increased after modification, but not too much, and relatively level of strain remained low. This is in agreement with the study done by Chung and his co-authors in 2004. They assessed the retention properties of different attachment systems for implant overdenture by measuring the peak load to dislodgement and strain at dislodgement. According to their study many attachment systems with patrix and matrix configuration have a relatively low strain at dislodgement value (less than 2). Physically, it may be related to snap action during insertion and removal of the overdenture.[23]

Increasing strain of the modified attachments was associated with increase of retention. This result resembles the findings of the study carried out by Elkerdawy and Radi in 2011. They evaluated stress configurations and retention of ball and socket and two telescopic attachments with different angles of convergence retaining an implant supported overdenture. They measured the retention with UTM and also microstrain by using strain gauges. Retention test revealed higher retention values with the ball and socket attachment. Meanwhile, the comparison revealed significantly higher microstrain values around the implants in the ball and socket design. Because the retention of the ball and socket attachment was higher than the telescopes, resistance to upward denture displacement appeared to be greater, resulting in the higher recorded microstrain values. Thus, the basic biomechanical principals would suggest that the greater the potential retention of an attachment, the greater the force that could be delivered to the abutment. Based on these results, there tends to be a correlation between the retention of the attachments and the strains transmitted to the implants or abutments. The greater the retention of the attachments, the more the transmitted stresses.[24]

All attachments exhibited increase of stress at dislodgement following modifications, except PV attachment which revealed reduction in stress level after modification. Stress reduction of modified PV, also may be related to increase in the surface area of this attachment. Because stress is calculated through dividing the force on surface area and has reverse relation with the stress. Consequently, dramatic increase of stress of PS may be due to smallest surface area of this attachment after modification.
As a result, among three attachments used in this study, modification of PV attachment created more surface area, a tighter fit, and more retention in addition to stress reduction at the time of dislodgement. The PS attachment demonstrated increase in retention as well but both stress and strain were increased after modification. While OT attachment showed reduction in retention and increased stress and strain after modification. Since determination of a clinically acceptable degree of retention should be made relative to prosthesis behavior during function and the patient's ability to adequately place and remove the prosthesis.[18] Therefore further in vivo and in vitro studies should be accomplished to assess the results of this laboratory investigation.
Furthermore, the wide range of commercially available brands and models of attachments and broad variability in study methods preclude direct comparisons with other studies.

Conclusion

With the limitation of this study the following conclusions can be drawn. Retention of removable partial denture can be increased through simple modification in attachment. The modified PV attachment demonstrates the highest retentive force with relatively low strain and stress at dislodgment. The PS attachment demonstrates increase in retention with greater increase of strain and stress at dislodgement after modification. We recommended further in vivo and in vitro study to evaluate clinical applicability of these modifications.

Conflicts of interest

The authors report no conflicts of interest.

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