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Comparison of Retention and Strain Energies of Stud Attachments for Implant Overdentures

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Abstract

Purpose: The retentive forces and the strain energies absorbed during dislodging of implant overdenture stud attachments are useful parameters to consider in the selection of attachments. The purpose of this study was to compare the retentive forces and strain energies of the Nobel Biocare standard ball, Nobel Biocare newer generation ball (Yorba Linda, CA), Zest Anchor, Zest Anchor Advanced Generation (Escondido, CA), Sterngold-Implamed ERA white, and Sterngold-Implamed orange attachments (Attleboro, MA) on an implant-retained in vitro overdenture model.
Materials and Methods: The attachments were tested using two permanently placed Brånemark system implants on a test model attached to an Instron machine. Each attachment had one part embedded in a denture-like housing, and the other part screwed into the implants. Dislodging tensile forces were applied to the housings in two directions simulating function: vertical and oblique. Eight tests were done in two directions with six specimens of each attachment. Retentive forces generated and strain energies absorbed during displacement were determined. A 1-way ANOVA followed by the Tukey studentized range test was used to determine groups that were significantly different at the $p < 0.05$ level.
Results: The Zest Anchor Advanced Generation attachment had significantly the highest retentive vertical and oblique forces [37.2 (5.5) N and 25.9 (3.2) N, respectively]. The Zest Anchor had the lowest vertical force [10.8 (4.2) N], and Nobel Biocare Standard had the lowest oblique retentive force [10.6 (3.0) N]. The Nobel Biocare Standard Ball attachment had the highest strain energies [29.7×10^{-3} (11.9×10^{-3}) J, 30.3×10^{-3} (14.3×10^{-3}) J, respectively, in the vertical and oblique directions]. The Sterngold-Implamed ERA White and Zest Anchor had the lowest strain energies [5.3×10^{-3} (3.2×10^{-3}) J and 4.5×10^{-3} (1.1×10^{-3}) J, respectively, in the vertical and oblique directions].
Conclusion: The retentive forces and strain energies of implant overdenture stud attachments are different and should be considered during prosthesis selection.

An attachment is a mechanical device for the fixation, retention, and stabilization of a dental prosthesis.[1] The concept of attachment fixation for tooth-supported overdentures originated in Switzerland around 1898, and Gilmore popularized it 60 years ago.[2] The implant-retained overdenture consists of: the implant; the abutment, which contains one of the mating attachment components depending on the system used; and the overdenture, which houses the counterpart attachment component.[3]

When complete dentures are converted into implant-retained overdentures using attachments, masticatory efficiency is improved. Most of the information for selection and use of attachments is derived from clinical experience.[4-6] The most economical and commonly used attachments are the stud-type attachments. Selection factors of attachment systems are the amount of space available, maintenance requirements, load distribution to the mucosa and to the implants, and the degree of retention.[7] Investigators have found a direct relationship between prosthesis retention and patient satisfaction.[8-10]

In vitro investigations of retention of attachments used on teeth[11-14] as well as implants[15] show that retention is influenced by attachment type and design,[11,12] wear of components,[13,14] and implant angulation.[15] Petropoulos et al[16] examined the retention and the time it takes to release the overdenture of five different attachments on a mandibular implant-retained overdenture model. Newer generations of some of the previously studied attachments have been made available by their manufacturers. While improvement in retention has been reported,[17] there is no information on improvements in longevity. The purpose of this current investigation was to compare the retentive forces needed to be overcome before complete separation of six stud attachments from the implant abutments during functional dislodgement. The energy absorbed (strain energy)[18] by the attachment components during complete disengagement from the implant abutments was investigated as a potential predictor of distortion of the attachments. Clinically, the strain energy may be an important parameter and has not been previously reported. It may be speculated that the higher the energy absorbed by the attachment as it is being removed from the implant abutment, the greater the distortion of the retentive elements.

Materials and methods

Attachment systems: The stud attachments examined are listed in Table 1 and shown in Figure 1. Abbreviations for group names are listed in Table 1. The methodology of this investigation was similar to that of Petropoulos et al.[16] Six specimens of each system were evaluated. Each specimen was subjected to eight measurements.

Test model: An acrylic resin mandibular test model was used to simulate the mandible. Two Brånemark system implants (Nobel Biocare, Yorba Linda, CA), 3.75 mm in diameter and 10 mm in length, were placed in parallel positions in the symphyseal regions. All tests were performed on this model. A cast chrome cobalt framework was fabricated to act as a denture base in the edentulous regions. This framework remained attached to the overdenture housings throughout the experiment. During testing it was lifted off the test model as one unit with the overdenture housings.

The overdenture housing was an acrylic resin removable component occupying the most anterior region where the cast chrome cobalt framework encircled the two implants. Its purpose was to hold the implant attachments being studied while the counterpart attachment components remained screwed into the test model implants. A prototype housing was fabricated from VLC blue Triad Material (Dentsply, York, PA) and duplicated in clear orthodontic acrylic resin (Caulk, Milford, DE). Thirty-six overdenture housings were fabricated using the prototype.

All attachment systems were activated by screwing the keyway or key component of the abutment into the implants and by positioning its counterpart attachment on top with its spacer. The attachment components were embedded in the housing using VLC Triad Reline material. For confirmation of positive seating of the overdenture housings onto the framework, holes on the housings were used as reference points, and they were checked for alignment with the nuts of the framework for all the specimen attachments.

Materials testing machine: A series 5500 Instron Materials Testing Machine (Instron, Canton, MA) with a computer interface (Series IX Materials Testing Software Program, Instron) was used to test the six attachment systems. A 50.8-mm/min crosshead speed was used for vertical separation of the specimens tested. This speed has been reported as an approximation

Table 1 Implant attachment systems examined

Attachment type (abbreviation)	Manufacturer	Components
Nobel Biocare Standard Ball (3.5 mm) (NBS)	Nobel Biocare	12 ball abutments; 12 plastic caps with rubber o-rings; 12 spacers
Nobel Biocare 2.25 mm diameter ball (newer generation ball) (NBNG)	Nobel Biocare	12 ball abutments; 12 metal caps with spring; 12 spacers
Zest Anchor (ZA)	Zest Anchors, Inc.	12 Zest implant abutments; 12 Zest operatory patrices with spacers
Zest Anchor Advanced Generation (ZAAG)	Zest Anchors, Inc.	12 Zest implant abutments; 12 Zest patrices with spacers
Sterngold-Implamed ERA (SEO)	APM Sterngold-Implamed	12 zero-degree abutments; 12 black processing patrices; 12 orange patrices
Sterngold-Implamed ERA (SEW)	APM Sterngold-Implamed	12 zero-degree abutments; 12 black processing patrices; 12 white patrices

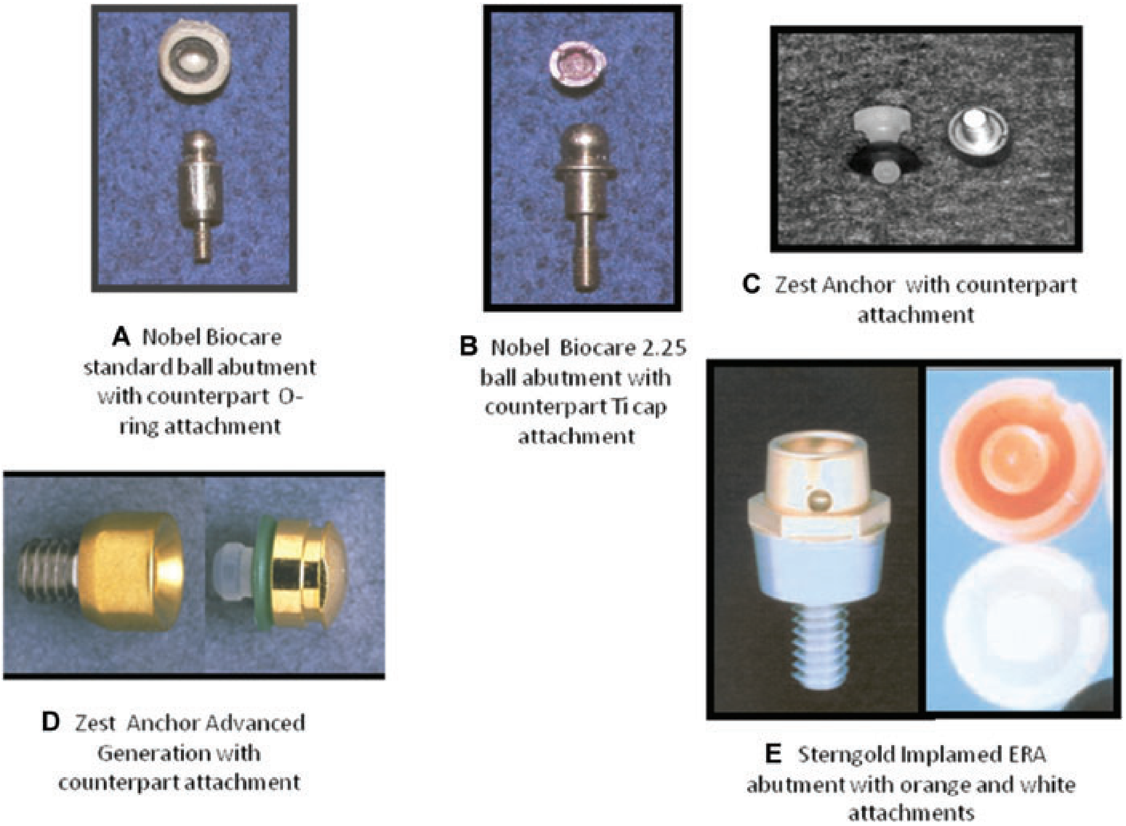

Figure 1 Attachments used in the study.

of the speed of movement of a denture from the ridge during mastication.[16]

The test model was attached to a stainless steel plate centered beneath the crosshead of the Instron Machine with adhesive (Scotch VHB joining systems, Scotchbond 3M, Minneapolis, MN). The model was positioned so the dislodging forces of the three-point pull were always directly vertical to the path of withdrawal of the housing and the framework. The entire framework was seated on the test model using the retromolar pads as positive seating position.

The abutments of the specimens tested were screwed into the Brånemark system implants in the test model. Each attachment overdenture specimen corresponding to the abutment attachment was secured within the framework by nuts, washers, and screws.

An S hook No. 1 with a 6.2-cm metal chain was locked into place in the center of the load cell. From its free end, a metal triangular plate with three tapped holes, one at each apex, and one tapped hole in its center, was attached to this chain by an O-ring screw screwed into the center of this triangular plate.

The chains were adjusted by tightening the O-ring screws connected to the triangular metal plate before each measurement to reduce slack to a minimum. The instrument was electronically calibrated and balanced, to account for the weight of the chains.

A three-point vertical pull applied by the Instron Materials Testing Machine to dislodge the housing was used to determine a vertically directed retentive force. Following this, the chain located in the right molar area was disconnected, and the two legs of the chain were attached to the two loops corresponding to the left molar and central incisor areas. The two-point vertical force needed to dislodge the housing was recorded as an obliquely directed retentive force.[19] The strain energy absorbed during dislodgement of the attachment was recorded for each direction of dislodgement.

Mean retentive forces and strain energy obtained for each attachment were subjected to 1-way ANOVA followed by pairwise comparisons using the Tukey studentized range test.[20] Significant differences were determined at the $p < 0.05$ level. Each of the four performance measurements (vertical and oblique retentive forces and vertical and oblique strain energy) were analyzed separately.

Results

A load versus displacement plot was obtained for each attachment system. The strain energy was calculated from the area under the load versus displacement curve using Series IX Materials Testing software. Statistically significant differences at the $p < 0.05$ level were found among the six attachments for each of the performance measurements (retentive force with vertically directed dislodging forces, retentive force with obliquely directed dislodging forces, strain energy with vertically directed dislodging forces, and strain energy with obliquely directed dislodging forces). For each performance measurement, the mean values and standard deviations are indicated in Figures 2–5.

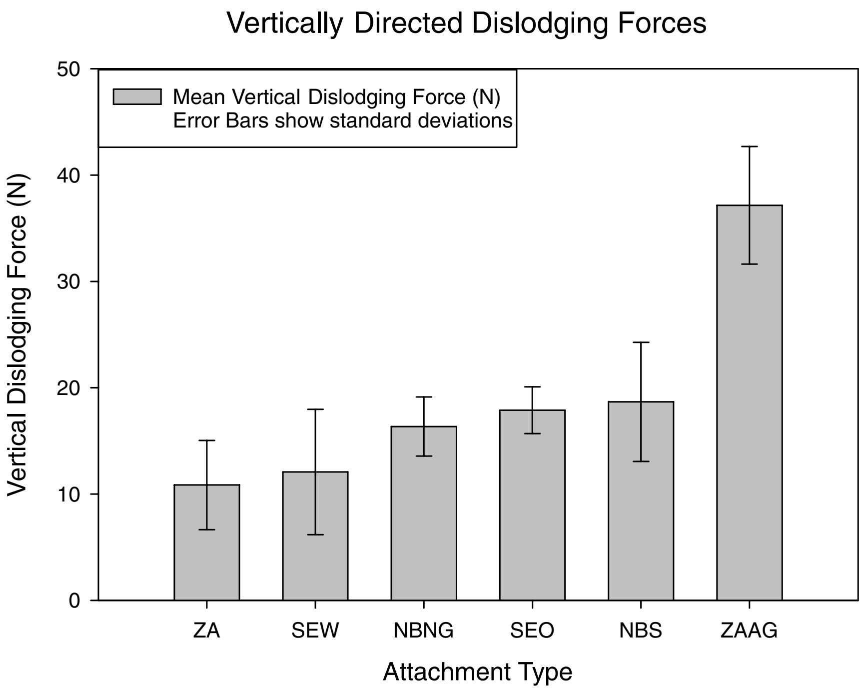

Figure 2 Mean values and standard deviations (N) of vertically directed dislodging forces of the six implant attachments for the NBS (Nobel Biocare standard ball), NBNG (Nobel Biocare 2.25-mm diameter ball), ZA (Zest Anchor), ZAAG (Zest Anchor Advanced Generation), SEO (Sterngold ERA orange), SEW (Sterngold ERA White).

Vertically directed retentive forces

The Zest Anchor Advanced Generation (ZAAG) attachment had significantly the highest retentive force compared to all other attachment systems (Fig 2). The Nobel Biocare standard ball (NBS) attachment had the next highest retentive force when compared to all other attachment systems (Fig 3) and was not statistically different from the Sterngold ERA orange (SEO), Nobel Biocare new generation (NBNG), Sterngold ERA White (SEW), and the Zest Anchor (ZA) attachment systems. The ZA attachment had the least amount of retentive force when compared to the other attachments (Fig 2).

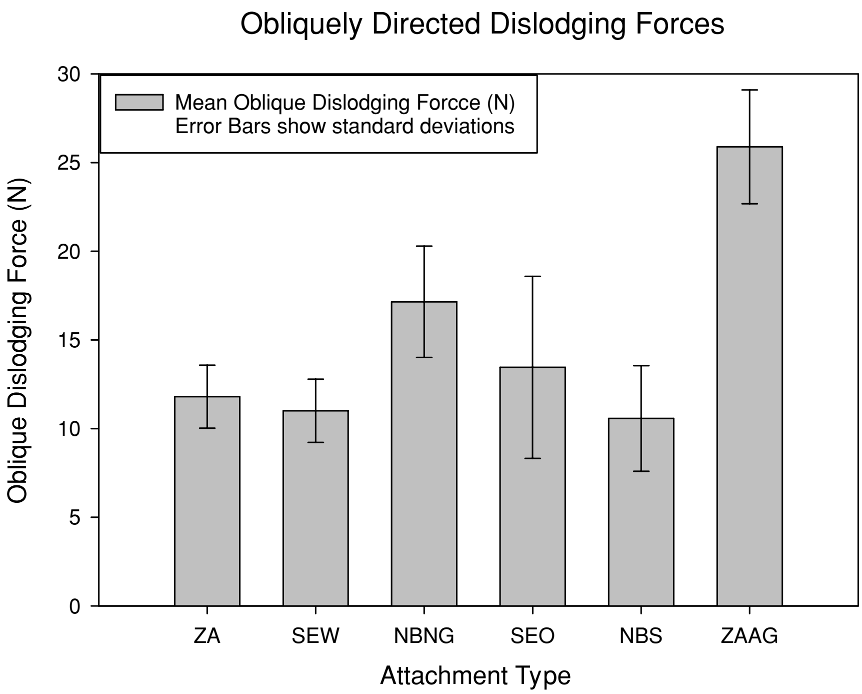

Figure 3 Mean values and standard deviations (N) of obliquely directed dislodging forces of the six implant attachments for the NBS (Nobel Biocare standard ball), NBNG (Nobel Biocare 2.25-mm diameter ball), ZA (Zest Anchor), ZAAG (Zest Anchor Advanced Generation), SEO (Sterngold ERA orange), SEW (Sterngold ERA White).

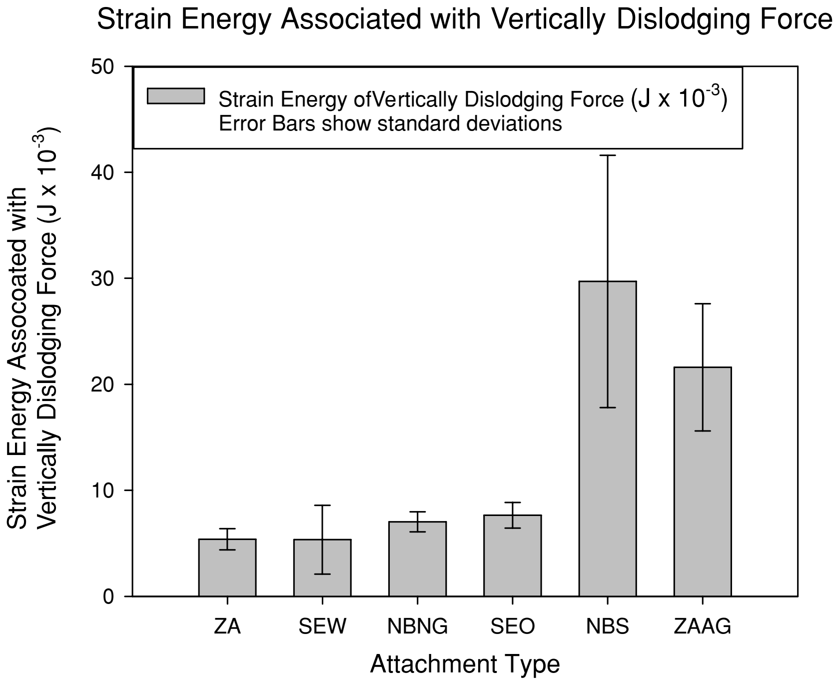

Figure 4 Mean values and standard deviations ($J \times 10^{-3}$) of the strain energy associated with vertical dislodging force measurements of the six implant attachments. NBS (Nobel Biocare standard ball), NBNG (Nobel Biocare 2.25-mm diameter ball), ZA (Zest Anchor), ZAAG (Zest Anchor Advanced Generation), SEO (Sterngold ERA orange), SEW (Sterngold ERA White).

Obliquely directed retentive forces

The ZAAG attachment had significantly the highest measured retentive force compared to all other attachment systems. The NBNG attachment had the next highest measured retentive force and was not statistically different from the SEO and ZA attachments. The NBS had the lowest amount of measured retentive force and was not statistically different from the SEO, ZA, and SEW attachments (Fig 3).

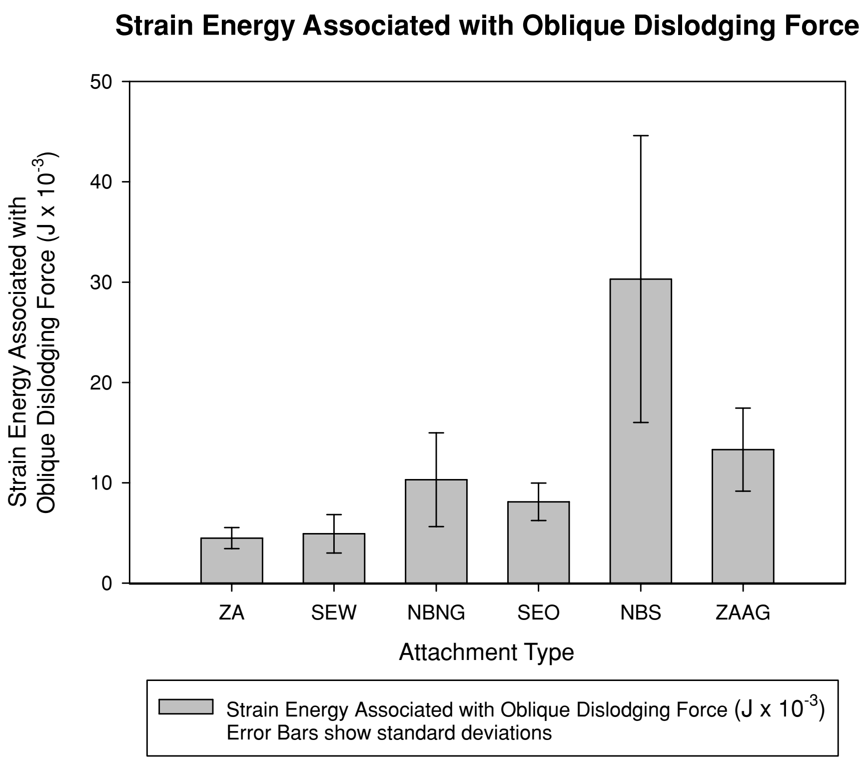

Figure 5 Mean values and standard deviations ($J \times 10^{-3}$) of the strain energy associated with oblique dislodging force measurements of the six implant attachments. NBS (Nobel Biocare standard ball), NBNG (Nobel Biocare 2.25-mm diameter ball), ZA (Zest Anchor), ZAAG (Zest Anchor Advanced Generation), SEO (Sterngold ERA orange), SEW (Sterngold ERA White).

Strain energy for vertically directed dislodging forces

The NBS attachment had the highest measured strain energy overall (Fig 4). The strain energy was significantly higher than ZA, NBNG, SEW, and SEO attachments, but was not statistically different from the ZAAG attachment. The SEW attachment had the lowest measured strain energy, but was not statistically different from the ZA, NBNG, and SEO attachments (Fig 4).

Strain energy for obliquely directed dislodging forces

The NBS attachment had significantly the highest measured strain energy overall (Fig 5). The ZA attachment had the lowest measured strain energy, but was not statistically different from the ZAAG, NBNG, SEO, and SEW attachments (Fig 5).

Discussion

Lack of retention is the most frequent problem with existing conventional complete dentures. This handicaps the patient both in mastication and in social situations due to fear of losing the dentures.[21] If a denture is easily dislodged during speech or eating, the embarrassment experienced can be mentally traumatic. A retentive denture contributes dramatically to patient acceptance of the definitive prosthesis.[22] This investigation studied the different stud attachments' retention also referred to as the break load, "breakaway force,"[17] or "pull-out force."[12,14,23] The energy absorbed by the attachments during dislodgement, the strain energy, was also measured.

The results showed that the most retentive and stable attachment in terms of the break load measurements with vertically and obliquely directed dislodging forces was the ZAAG attachment system. It was significantly the most retentive compared to the other five attachments. This may be attributed to its design configuration, which is different from the others (with the exception of its predecessor, the ZA). The design is an intraradicular attachment, in which the key element (patrix) forms part of the denture base and engages a specially produced depression within the implant abutment (keyway) (matrix), which is made from stainless steel and coated with a titanium alloy. The key element, which is the retentive feature of the ZAAG attachment, is a nearly parallel-sided, cylindrical plastic nylon band that is longer and wider when compared to its predecessor, the ZA. The ZA in contrast, has a small short diameter band and at its tip a small ball. Therefore, the superior retention of the ZAAG over the ZA is due to the increased surface area of the larger and wider retentive band. This is analogous to a tooth preparation, in which longer preparations will have more surface area and the crown will be more retentive.[24] Additionally, due to the nearly parallel-sided walls of the plastic band, the taper is minimal, yielding greater retention. The retention of a surface with two opposing walls will increase as the taper decreases or is nearly parallel.[25]

The design of the ball attachments examined (NBS and NBNG) is extraradicular, in which the key element (patrix) projects from the implant abutment. The standard ball (3.5-mm diameter) (patrix), which is made from Ti, uses a plastic retention cap (matrix) housing a rubber O-ring for retention. The plastic O-ring is flexible and able to move beyond the undercut (the height of contour) of the Ti ball and achieves its retention in this manner.[17] The NBNG ball (2.25-mm diameter) has the option of two types of metal retention caps: one is Ti, the other is made of gold. In this study, the Ti cap was tested. The mechanism of retention for this attachment is a Ti spring embedded in its cap. The gold cap, on the other hand, is designed with "pedals" that allow for an adjustable retention. When comparing the NBNG to its predecessor (NBS) for the obliquely directed dislodging forces, NBNG had a significantly higher retentive force. The fact that the newer generation ball shows more retention than its predecessor may be due to its universal hinge movement design, which allows it to pivot and rotate more than the NBS; however, for the vertically directed dislodging forces the NBS (standard ball) had the next highest retention following the ZAAG, but was not significantly different from the newer generation ball attachment, the NBNG.

The Sterngold-Implamed ERA attachments are classified as extraradicular resilient attachments. The key elements (patrices) are made of nylon and are color coded by the manufacturer according to the amount of retention (white, orange, blue, gray);[26] recently two more retentive elements have been added: yellow and red (hierarchy of retention from least to most). This feature allows the clinician to vary the retention if necessary. In this investigation, the orange and white ERAs were compared (SEO and SEW, respectively). SEO had the next highest retention for the vertical dislodging forces, following the NBS, but was not significantly different from the SEW, NBS, NBNG, and ZA attachments. When comparing the SEO to the SEW, although the manufacturer claims that SEO has higher retention than SEW, the differences were not statistically significant for the oblique dislodging forces. The mechanism for varying the amount of retention between the white, orange, blue, gray, yellow, and red is that the nylon patrices (key elements) become increasingly oversized in comparison to the stainless steel with titanium nitride coating [keyway (matrix) component]. This creates more surface area, a tighter fit, and more retention.

Previous investigations of attachments are in general agreement that loss of retentive force over time is inevitable. This loss of retention has been attributed to wear of attachment components. Although the mechanisms of wear are poorly understood,[27] we speculate that loss of retention may also be related to deformation mechanisms operative during insertion and removal of attachment components. Chung et al have associated a low strain to dislodgement of a patrix and matrix configuration attachment with a snap action during insertion and removal of the overdenture. High strain at dislodgement of the Locator white patrix and Hader Bars with metal clips was associated with a high distortion of the retentive elements during insertion and dislodgement.[28]

The strain energy absorbed during insertion may be divided into elastic (recoverable) and plastic (permanent) components. Ideally, the contacting surfaces should undergo fully recoverable strain. If permanent deformation occurs, a rapid loss of retention will be observed as reported by Evtimovska et al.[29] The energy related to permanent deformation may be correlated to loss of retention.

Measurements of strain energy during removal and insertion may therefore provide some information relative to this deformation. Furthermore, viscoelastic creep may also contribute to the loss of retention, particularly of plastic contacting surfaces. When subjected to the same forces during function, plastic-lined attachments are more likely to undergo permanent deformation and creep, leading to more rapid loss of retention when compared to metallic components. Plastic deformation and creep may explain the absence of a correlation between weight loss due to wear and loss of retention of attachments in previous studies.[30-32]

The results showed the NBS to have the highest strain energy when complete disengagement of the attachment components occurred for both the vertically and obliquely directed dislodging forces. This energy absorbed by the attachment is the measure of the amount of work done to stretch the plastic O-ring component as it is overcoming the retentive undercut of the Ti part of the ball abutment. As the O-ring is stretched and removed from the metal ball, it goes back to its original shape. If the deformation is elastic, no loss of retention is expected. If permanent deformation occurs, incomplete recovery is likely to lead to some loss of retention. The SEW and the ZA had the lowest measured strain energy of all the attachments. This finding may be clinically related to a snap action during insertion and removal of these attachments.[28]

The results of this study did not provide a breakdown of elastic and plastic strain energies, limiting conclusions that can be drawn. Further studies on strain energies are needed to determine if a relationship exists between the type and quantity of energy and the degree of distortion of the retentive portion of the attachment. The lack of an in vivo environment, with saliva as a lubricant, and accompanying thermal changes is a limitation of direct application of the data to the clinical situation. Also, in vitro experiments more closely replicating the oral environment, as well as short- and long-term clinical investigations are needed to validate data obtained in vitro.

The values of retention reported in this study are similar to those previously reported by Petropoulos et al,[16,17] Williams et al,[12] and Chung et al.[28] The strain energy associated with dislodging has not been previously reported and may have a bearing on the degree of distortion of the attachment.

Conclusions

Within the constraints of the study, the following conclusions have been drawn:

1. All newer generation attachment systems showed improvement, with higher retention values in at least one direction of the dislodging forces simulating function of an overdenture prosthesis.
2. The strain energy generated during dislodging is highest for NBS and may imply greater distortion of the retentive components of the attachment.

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