Maximum Dislodging Forces of Implant Overdenture Stud Attachments

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Purpose: *The aim of this study was to compare the retention and stability of the Nobel Biocare standard ball (NBS), Nobel Biocare 2.25-mm-diameter ball (NB2), Zest Anchor (ZA), Zest Anchor Advanced Generation (ZAAG), Sterngold ERA orange (SEO), and Sterngold ERA white (SEW) attachments on an implant-retained overdenture model.* ***Materials and Methods:*** *The attachments were tested using 2 permanently placed Brånemark System implants on a test model that was attached to an Instron machine (crosshead speed 50.8 mm/minute). 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 3 directions simulating function: vertical, oblique, and anterior-posterior. Eight tests were done in 3 directions with 6 samples of each attachment. The dislodging forces generated measurements of the peak load (maximum dislodging force). A 1-way analysis of variance followed by the Tukey studentized range test was used to determine groups that were significantly different. All tests for significance were carried out at the .05 level of significance.* ***Results:*** *Results showed the ZAAG attachment to be the most retentive for the peak load measurement when subjected to vertically directed forces, with mean values and standard deviations of 37.2 ± 5.5 N. The next most retentive attachment was the NBS, followed by the SEO, NB2, SEW, and ZA. For obliquely directed forces, the ZAAG attachment was the most retentive, with mean values and standard deviations of 27.2 ± 4.2 N. The next most retentive was the NBS, followed by the NB2, SEO, ZA, and SEW. For anterior-posteriorly directed forces, results showed the NBS had the highest measured retentive force, with mean values and standard deviations of 34.6 ± 18.8 N, but this was not statistically different from the NB2 and ZAAG; this was followed by the SEO, SEW, and ZA.* ***Discussion:*** *There has been a marked resurgence in the treatment of patients with overdentures using implant attachments as retentive devices. The maximum force developed (a measure of retention) as the implant stud attachments were resisting removal from the implant abutments was determined.* ***Conclusions:*** *Based on the present study, the clinician may be able to make empirical decisions on attachment selection, depending on the amount of retention desired and the specific clinical situation.* (INT J ORAL MAXILLOFAC IMPLANTS 2002;17:526–535)

Key words: *denture retention, denture precision attachment, overdenture, tensile strength*

In patients with edentulous mandibles, the stability and retention of a complete denture is a common problem that can be managed by the selective placement of implants.[1] Basically 3 different concepts based on the Brånemark System have been established for implant prostheses in the edentulous mandible[1]: *(1)* implant-supported fixed prosthesis, *(2)* removable implant-supported overdenture, and *(3)* combined implant-retained/soft tissue–supported overdenture prosthesis. The current investigation studied the retention of various stud attachments designed for a prosthesis as described in the third concept. The advantages of this type of prosthesis are a reduced number of implants, a simpler surgical procedure, and an easier restorative technique because of the application of prefabricated attachments.[2]

The implant-retained/soft tissue–supported overdenture consists of[3] *(1)* the implant; *(2)* the abutment, which contains the keyway or key attachment component, depending on the system used;

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Table 1 Implant Attachment Systems Examined

Attachment type	Manufacturer	Components
Nobel Biocare standard ball (3.5 mm)	Nobel Biocare Yorba Linda, CA	12 ball abutments, 5.5-mm, 12 plastic caps with rubber O-rings, 12 spacers
Nobel Biocare 2.25-mm-diameter ball (newer ball)	Nobel Biocare Yorba Linda, CA	12 ball abutments, 5.5-mm, 12 titanium alloy caps with spring, 12 spacers
Zest Anchor	Zest Anchors Escondido, CA	12 Zest implant abutments, 5-mm, 12 Zest operatory males with spacers
Zest Anchor Advanced Generation	Zest Anchors Escondido, CA	12 Zest abutments, 5-mm 12 Zest gold-plated stainless steel cap with nylon males, 12 spacers
Sterngold ERA orange	Sterngold Attleboro, MA	12 zero-degree abutments, 5-mm, 12 black processing males, 12 orange males
Sterngold ERA white	Sterngold Attleboro, MA	12 zero-degree abutments, 5-mm, 12 black processing males, 12 white males

and *(3)* the overdenture, which houses the counterpart attachment. These mechanical devices or attachments are not new concepts for providing retention for overdentures. The original concept of attachment fixation for overdentures originated in Switzerland around 1898, and Gilmore popularized it 60 years ago.[4] With the current advanced and successful techniques of osseointegration, endosseous implants are being used in the same manner as were tooth roots more than 100 years ago, and they have been shown to be reliable abutments for both retention and support of overdentures.[5]

Currently there are many different attachments available for use with implant-retained/soft tissue–supported overdentures. Factors that come into play for selection 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.[1]

The most popular of the attachment systems and the simplest to use are the stud attachments.[6] The stud attachments are divided into 2 groups: *(1)* extraradicular, in which the key element projects from the root surface of the preparation or implant, and *(2)* intraradicular, in which the key element forms part of the denture base and engages a specially produced depression within the root contour or implant.[6] These attachments can provide additional support, stability, and retention.[6]

Denture retention is defined as the resistance to vertical and torsional stresses, or the resistance of a denture to removal in a direction opposite that of its insertion.[7] Investigators have found that a direct relationship exists between prosthesis retention and patient satisfaction.[8–10] The purpose of this study was to determine whether there were any differences in the peak load measurement, a measure of retention and stability (maximum forces developed before complete separation of attachment components) for vertically, obliquely, and anterior-posteriorly directed dislodging forces of 6 commonly used stud attachments. Previous in vitro investigations have studied the retention for attachments on teeth.[11–13] A previous study measured the retention of attachments for overdentures on an implant-retained model.[14] Some of the previously studied attachments have been modified by their manufacturers, and the current study examined the newer generation of attachments, as well as their predecessors. The following popularly used stud attachments were examined on an implant-retained overdenture model (Table 1):

- The Nobel Biocare standard ball (NBS) (Nobel Biocare, Yorba Linda, CA)
- The Nobel Biocare newer-generation ball, the 2.25-diameter (NB2)
- The Zest Anchor (ZA) (Zest Anchors, Escondido, CA)
- The newer-generation Zest Anchor Advanced Generation (ZAAG)
- The Sterngold ERA orange (SEO) (Sterngold, Attleboro, MA)
- The Sterngold ERA white (SEW)

Fig 1 Acrylic resin mandibular test model with 2 Brånemark System implants placed in the symphyseal region. Also shown is the cast chrome-cobalt framework with 4 withdrawal loops for the application of tensile forces by the Instron Materials Testing Machine. Four 3-mm-diameter stainless steel nuts were soldered to the framework. These nuts allowed the sample overdenture housings to be secured and fastened with screws, nuts, and bolts.

MATERIALS AND METHODS

The methodology and statistical analysis used in this investigation were similar to that of Petropoulos and coworkers[14] and are described in more detail below.

Attachment Systems

The attachment systems examined are shown in Table 1. Six samples of each system were used. They were subjected to 8 measurements. All attachment systems had varying amounts of retention preset from their manufacturer. Because these attachment systems are prefabricated by their respective manufacturers, they are standardized in shape, size, and fit. To some degree, this helped control variability within the groups.

The Test Model

An acrylic resin mandibular test model was used to simulate the mandible (Fig 1). No undercuts were present. Two Brånemark System implants (Nobel Biocare), 3.75 mm in diameter and 10 mm in length, were placed in parallel positions in the symphyseal region. Two implants have been found to be adequate for an implant-retained overdenture model.[15] This is the model on which all the tests were performed. Because the edentulous regions were without undercuts, retention was achieved from the anterior region where the implants were placed. Although this was an in vitro investigation, an attempt was made to simulate the clinical situation. A cast chrome-cobalt framework was fabricated to act as a denture base in the edentulous regions. Overdentures can be fabricated with either acrylic resin or metal bases.[16] The advantage of using a metal framework instead of an acrylic resin base was that the framework remained constant for all tests and enabled the use of the same test model and overdenture base for all attachment systems (Fig 1).

The different overdenture attachment systems were interchanged on the framework. Four 3-mm-diameter stainless steel nuts were soldered to the framework: 2 in the most anterior region of the outer limits of the framework, and 2 in the most posterior region of the implants. These steel nuts allowed the overdenture housings that contained the different overdenture attachment systems to be secured and fastened onto the framework and interchanged as required. Four withdrawal loops were attached to the metal framework. This framework remained attached to the overdenture housings throughout the experiment, and it was lifted off the test model as a unit with the overdenture housings. It functioned like the acrylic resin flanges of an overdenture in the edentulous regions (Fig 2a).

Fabrication of Overdenture Housing

The overdenture housing (Fig 2b) was the acrylic resin removable component occupying the most anterior region where the cast chrome-cobalt framework encircled the 2 implants. Its purpose was to activate the implant attachments being studied, while the counterpart attachments remained screwed into the test model implants. The prototype housing was fabricated from VLC Blue Triad material (Dentsply, York, PA). The prototype housing was placed in a denture-duplicating flask (Implant Innovations, West Palm Beach, FL) that contained the condensation silicone putty Zetalabor (Zhermack, Rovigo, Italy). The flask was opened after the material had set for 20 minutes, and the prototype was removed. An impression was made of the prototype housing. Clear orthodontic resin and liquid monomer (Dentsply/Caulk, Milford, DE) were mixed according to the manufacturer's recommendations and were placed inside the flask. The flask was submerged in warm water in a pressure cooker under air pressure (15 psi) for 35 minutes. A total of 36 overdenture acrylic resin housings were fabricated.

Fabrication of Sample Attachments

All attachment systems were activated by screwing the keyway or key component of the abutments (depending on which system was used) into the implants and by positioning its counterpart attachment on top with its spacer. VLC Triad reline material (Dentsply) was

Fig 2a The Sterngold ERA white attachment (SEW) seated on test model with screws, nuts, and bolts securely fastened.

Fig 2b The Nobel Biocare standard ball overdenture sample attachment (NBS). VLC Triad reline material picked up the sample attachments. One part of the attachment is embedded in the overdenture housing, and its counterpart is screwed into the test model implants.

used to activate the attachment components. Each sample overdenture attachment system had 1 part embedded in the overdenture housing and the other part screwed into the test model implants (Fig 2b). For confirmation of positive seating of the overdenture housings onto the framework, the holes of the housings were used as reference points, and they were checked for alignment with the nuts of the framework for all the sample attachments.

Materials Testing Machine

The series 5500 Instron Materials Testing Machine (Instron, Canton, MA) with a computer interface was used to test the 6 different attachment systems. The horizontal load frame, which was driven by a motor, induced the vertical separation of the samples tested. This was set at a constant crosshead speed, 50.8 mm/minute, which has been reported to approximate the speed of the movement of the denture away from the ridge during mastication.[17]

The test model was stabilized with a clamp to a stainless steel plate centered beneath the testing machine. The model was positioned so that the dislodging forces of the 3-point pull were always directed vertically 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 samples tested were screwed into the implants in the test model. Each attachment overdenture sample corresponding to the abutment attachment was secured within the framework by nuts, washers, and screws.

A No. 1 S hook with a 6.2-cm metal chain was locked into place in the center of the load cell. From its free end, a triangular metal plate with 3 tapped holes (1 at each apex) and 1 tapped hole in its center was attached to this chain by an O-ring screw, which was screwed into the center of this triangular plate (Fig 3a). The O-ring screw on the right side of the triangular plate was connected to a chain. A No. 2 S hook joined the end of this chain with the right side molar area on the framework. The O-ring screw on the left side of the triangular plate was connected to a chain. A No. 3 S hook connected the end of this chain to the left side molar area on the framework. The anterior segment of the framework included 2 loops. An anterior wire was passed from the loop in the facial area to the loop in the lingual area. A fourth chain was attached at one end to the center of the arc created by the anterior wire and attached at the other end to an O-ring screw, which was positioned at the center of the plate. This acted to resolve the forces in the anterior region.

The chains were adjusted by tightening as necessary the O-ring screws connected to the triangular metal plate before each measurement to reduce slack to a minimum (Fig 3a). The instrument was electronically calibrated and balanced, accounting for the weight of the chains.

A 3-point vertical pull was used to determine retention against a strictly vertically directed dislodging force parallel to the path of insertion and withdrawal (Fig 3b). Following this, the chain located in the right molar area was disconnected, and the 2 legs of the chain were attached to the 2 loops corresponding to the left molar and central incisor areas. This resulted in an oblique lifting force, simulating function. Following that, the chains in the left and right molar region remained, while the chain in the anterior region was removed.

Fig 3a *(Left)* The metal triangular plate with O-rings connected to the load cell from one end and to the cast-metal overdenture framework from the apices. This allowed for adjustment of slack in the chains.

Fig 3b *(Right)* The 3-point vertically directed dislodging force applied to the Zest Anchor Advanced Generation (ZAAG) overdenture sample attachment.

This resulted in a rotational pull, an anterior-posterior lifting force (ie, lifting forces applied to the distal extension bases) simulating function.[18] This type of pull was a measure of denture stability. Stability is the resistance to horizontal and rotational forces that prevents lateral or anterior-posterior shunting of the denture base.[19]

The dislodging tensile forces applied by the testing machine yielded the peak load measurement (maximum dislodging forces): the maximum force that developed before complete separation of the attachment components from the implant abutments.

Statistical Analysis

Statistical analysis of the experimental data followed directly from the single-factor randomized experimental design. Each of the 3 performance measurements—vertical, oblique, and anterior-posterior peak load—was analyzed separately.

A power analysis for detecting a difference between mean forces was performed to give an indication of the sensitivity of the proposed design and analysis. In this analysis, the 6 replicate and 6 overdenture attachments design was used and assumed a within-treatment standard deviation of 4.9 N. (The observed sample standard deviation was 4.7 for vertical maximum load.) It was assumed that there were 2 groups of attachments consisting of 3 attachments each. If these 2 groups differ by 4.9, 7.4, or 9.8 N, then the respective powers for a 95% confidence level test are 0.53, 0.91, and 0.99.

For each of the 3 performance measurements, a 1-way analysis of variance (ANOVA) was performed. In a pairwise fashion, for the 6 overdenture attachment systems, there were a total of 15 pairwise comparisons. To control the overall error rate for those 15 comparisons, the Tukey studentized range or honestly significant difference test was used.[20] All pairwise comparisons were carried out using the .05 level of significance for the 2-sided Tukey studentized range test.

RESULTS

The results are presented in Tables 2 to 4. The statistical results can be summarized as follows. All 3 ANOVAs were significant at the .05 level or above, indicating that statistically significant differences existed among the 6 attachments for each of the performance measurements (peak load with vertically directed dislodging forces, peak load with obliquely directed dislodging forces, peak load with anterior-posteriorly directed dislodging forces). For each performance measurement, the pairwise comparisons that were significant at the .05 level, using the Tukey studentized range test, are indicated in Tables 2 to 4. Graphic representations are also shown (Figs 4 to 6).

Peak Load (Maximum Dislodging Force) Measurements for Vertically Directed Dislodging Forces

The ANOVA and the Tukey pairwise comparisons among all the attachments indicated the following comparisons were statistically significant at a 95% level of confidence ($P < .05$).

Table 2 Summary of Arithmetic Means of Attachment Comparisons of Peak Load (Maximum Dislodging Force) and the Tukey Pairwise Test for Vertically Directed Dislodging Forces

Implant attachment	Peak vertical load (N)
Zest Anchor Advanced Generation (ZAAG)	37.2
Nobel Biocare standard ball (NBS)	24.3
Sterngold ERA orange (SEO)	18.5
Nobel Biocare 2.25-diameter ball (NB2)	17.8
Sterngold ERA white (SEW)	12.7
Zest Anchor (ZA)	11.6

Vertical bars connect groups that are not significantly different. The Tukey pairwise multiple comparison test was used, with the overall familywise error rate set at .05.

Table 3 Summary of Arithmetic Means of Attachment Comparisons of Peak Load (Maximum Dislodging Force) and the Tukey Pairwise Test for Obliquely Directed Dislodging Forces

Implant attachment	Peak oblique load (N)
Zest Anchor Advanced Generation (ZAAG)	27.2
Nobel Biocare standard ball (NBS)	20.0
Nobel Biocare 2.25-diameter ball (NB2)	19.1
Sterngold ERA orange (SEO)	17.7
Zest Anchor (ZA)	12.5
Sterngold ERA white (SEW)	12.3

Vertical bars connect groups that are not significantly different. The Tukey pairwise multiple comparison test was used, with the overall familywise error rate set at .05.

Table 4 Summary of Arithmetic Means of Attachment Comparisons of Peak Load (Maximum Dislodging Force) and the Tukey Pairwise Test for Anterior-Posteriorly Directed Dislodging Forces

Implant attachment	Peak anterior-posterior load (N)
Nobel Biocare standard ball (NBS)	34.6
Nobel Biocare 2.25-diameter ball (NB2)	32.9
Zest Anchor Advanced Generation (ZAAG)	15.5
Sterngold ERA orange (SEO)	8.6
Sterngold ERA white (SEW)	8.4
Zest Anchor (ZA)	5.2

Vertical bars connect groups that are not significantly different. The Tukey pairwise multiple comparison test was used, with the overall familywise error rate set at .05. This analysis used log-transformed data.

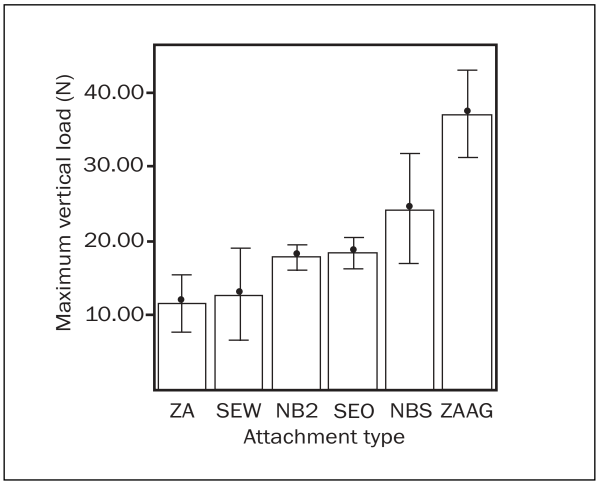

Fig 4 Arithmetic mean values and 95% confidence interval *(error bars)* of the maximum load measurements of the 6 implant attachments for the vertically directed dislodging forces. The confidence interval is based on the observed within-group standard deviation. NBS = Nobel Biocare standard ball; NB2 = Nobel Biocare 2.25-mm-diameter ball; ZA = Zest Anchor; ZAAG = Zest Anchor Advanced Generation; SEO = Sterngold ERA orange; SEW = Sterngold ERA white.

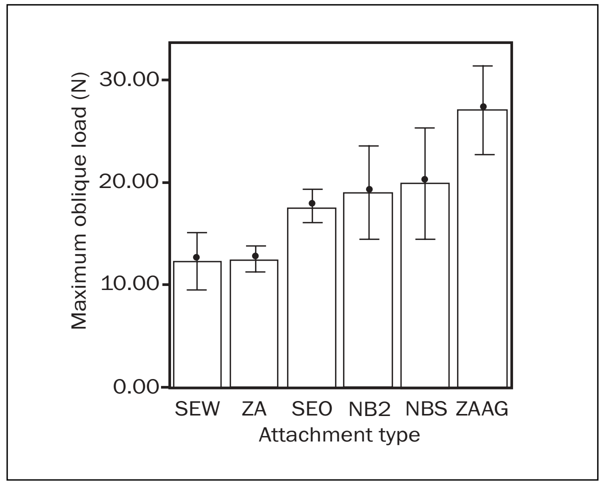

Fig 5 Arithmetic mean values and 95% confidence interval *(error bars)* of the maximum load measurements of the 6 implant attachments for the obliquely directed dislodging forces. The confidence interval is based on the observed within-group standard deviation. NBS = Nobel Biocare standard ball; NB2 = Nobel Biocare 2.25-mm-diameter ball; ZA = Zest Anchor; ZAAG = Zest Anchor Advanced Generation; SEO = Sterngold ERA orange; SEW = Sterngold ERA white.

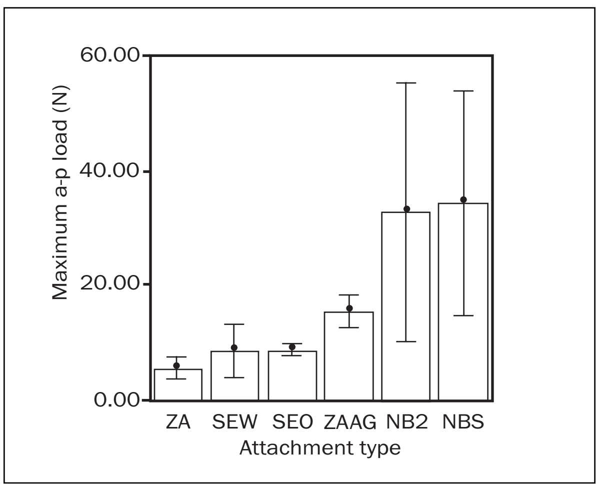

Fig 6 Arithmetic mean values and 95% confidence interval *(error bars)* of the maximum load measurements of the 6 implant attachments for the anterior-posteriorly directed dislodging forces. The confidence interval is based on the observed within-group standard deviation. NBS = Nobel Biocare standard ball; NB2 = Nobel Biocare 2.25-mm-diameter ball; ZA = Zest Anchor; ZAAG = Zest Anchor Advanced Generation; SEO = Sterngold ERA orange; SEW = Sterngold ERA white.

1. The ZAAG attachment had a significantly higher measured peak load than all other attachment systems.
2. The NBS had the next highest measured peak load when compared with all other attachment systems, but this was not significantly different from the NB2 and SEO attachment systems.
3. The ZA had the lowest measured peak load when compared with all other attachment systems and was not significantly different from the NB2, SEO, and SEW.

The ranking according to the means is summarized in Table 2 (ZAAG > NBS > SEO > NB2 > SEW > ZA). These results indicated that ZAAG ranked the highest in terms of the peak load in a vertical direction, a measure of retention, when vertically directed dislodging forces were applied.

Peak Load (Maximum Dislodging Force) Measurements for Obliquely Directed Dislodging Forces

The ANOVA and the Tukey pairwise comparisons among all the attachments indicated that the following comparisons were statistically significant at a 95% level of confidence ($P < .05$).

1. The ZAAG attachment had a significantly higher measured peak load than all other attachment systems.
2. The NBS, NB2, and SEO had the next highest measured peak load, and they were not statistically different from each other.
3. The SEW had the lowest amount of measured peak load and was not statistically different from the ZA and SEO.

The ranking according to the means is summarized in Table 3 (ZAAG > NBS > NB2 > SEO > ZA > SEW). These results indicated that ZAAG ranked the highest in terms of peak load, a measure of retention, when obliquely directed dislodging forces were applied.

Peak Load (Maximum Dislodging Force) Measurements for Anterior-Posteriorly Directed Dislodging Forces

For anterior-posterior forces, it was observed that there were substantial differences in the mean treatment effects, which resulted in large differences in the within-treatment standard deviations, with larger means associated with larger standard deviations (Fig 6). In this situation, it is known that the log transformations will result in more homogeneous within-treatment variances.[21] The ANOVA and the Tukey pairwise comparisons among all the attachments indicated the following comparisons were statistically significant at a 95% level of confidence ($P < .05$).

1. The NBS had the highest measured peak load, but was not statistically different from the NB2 and ZAAG attachment systems.
2. The least amount of retention was the ZA, which was not statistically different from the SEO and SEW attachment systems.

The ranking according to the means is summarized in Table 4 (NBS > NB2 > ZAAG > SEO > SEW > ZA). These results indicated that the NBS ranked the highest in terms of the peak load, a measure of stability when anterior-posteriorly directly dislodging forces were applied.

DISCUSSION

Over the past 3 decades there has been a marked resurgence in the treatment of patients with overdentures of the complete denture type. This is probably a result of a general increase in patients' dental knowledge and availability of newer attachment mechanisms that use osseointegrated implants.[22] An overdenture, once placed in the mouth, is subjected to a variety of forces applied in different directions. Retention can be considered as the force that resists withdrawal along the path of insertion. When analyzing the resistance to dislodgment (retention) of the implant attachments from the implant abutments, there are 2 aspects of retention: *(1)* the perspective of the patient, ie, the feeling of how secure the prosthesis is in place as the overdenture is removed and separated from the implant abutments (break load or breakaway force); and *(2)* the perspective of the clinician, ie, the measurement of the peak load (maximum dislodging force) as the overdenture is resisting removal from the patient's abutments. This investigation studied this second aspect of retention, the peak load measurement of the different stud attachments. This force has also been referred to in the literature[23] as "grip force," which is a measure of denture resistance to dislodgment. The resistance to dislodgment of the overdenture base to anterior-posterior forces, ie, the stability, was also measured.

The results showed that the most retentive attachment, in terms of the peak load measurements with vertically and obliquely directed dislodging forces, was the ZAAG attachment system. These measurements were significantly higher (with mean values of 37.2 N and 27.2 N, respectively) compared to the other 5 attachments. This may be attributed to its design configuration, which is different from the others. 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 a titanium alloy. The key element in the ZAAG, which is the retentive feature of this attachment, is a nearly parallel-sided, cylindric plastic band, which is longer and wider than its predecessor, the ZA. The ZA, in contrast, has a small, short-diameter, nylon band and a small ball at its tip. Therefore, 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 analogous to a tooth preparation, in which longer preparations will have more surface area and the crown will be more retentive.[24] Additionally, because of the nearly parallel-sided walls of the plastic band, the taper is minimal, yielding greater retention. The retention of a surface with 2 opposing walls will increase as the taper decreases or is nearly parallel.[25]

In contrast to the ZAAG and ZA attachments, the design of the ball attachments examined are extraradicular, in which the key element (patrix) projects from the implant abutment. When the NB2 was compared to its predecessor (the NBS) for the vertical and oblique dislodging forces, there were no statistically significant differences. The NBS (standard ball) had the next highest retention (24.3 N and 20.0 N, respectively for vertical and oblique dislodging forces). The standard ball (3.5 mm diameter) (patrix), which is made from titanium, uses a plastic retention cap (matrix) that houses 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 titanium ball and achieves its retention in this manner. The NB2 ball (2.25 mm diameter) has the option of 2 types of metal retention caps; one is titanium and the other is made of gold. In this study, the titanium cap was tested. The mechanism of retention for this attachment is a titanium spring embedded in its cap. The gold cap, on the other hand, is designed with "pedals" that allow for adjustable retention. Had the other ball attachment been tested, perhaps statistically significant differences might have been seen between the older- and newer-generation ball attachment systems, as well as the SEO attachment.

The Sterngold 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, grey, from least retentive to most retentive).[26] This feature allows the clinician to vary the retention if necessary. In this study, the orange and white ERAs were compared (SEO and SEW, respectively). The SEO had the third highest retention for the vertical dislodging forces (18.5 N) but was not significantly different from the NBS and NB2. Perhaps if the grey patrix had been used, which is more retentive than the white and orange, significant differences may have been observed. When the SEO and the SEW were compared, there were no statistically significant differences for the vertical, oblique, and anterior-posterior dislodging forces. The SEO did have higher measurements of the peak load compared to the SEW, which is to be expected since the manufacturer claims that the SEO provides higher retention than the SEW. The mechanism for the varying amount of retention between the white, orange, blue, and grey, is that the nylon patrices (key elements) become increasingly oversized in comparison to the titanium nitride-coated stainless steel matrices (keyway elements). This creates more surface area, a tighter fit, and more retention.

Subjection of the overdentures to dislodging forces in an anterior-posterior direction measured their stability (as opposed to retention, which was measured with vertically and obliquely directed dislodging forces). The NBS, NB2, and ZAAG attachments were not statistically significantly different with this type of dislodgement. The fact that these attachments had similar stability in this direction is not surprising, as they are all classified and all function as resilient "universal hinge" attachments, which allows pivoting and rotational movement.

As each attachment was dislodged in an anterior-posterior direction and their maximum dislodging forces were compared with the vertically directed dislodging forces, it was observed that the SEO, SEW, and ZA attachments had lower peak loads. The NBS, NB2, and ZAAG attachments actually increased their peak loads when the overdenture was dislodged in a rotational tipping force, creating instability to the overdenture. Again, this could be a result of their function as "universal hinge" attachments that allow rotational and pivoting movement, rendering them more stable in this direction.

CONCLUSIONS

The peak load (maximum dislodging force) was determined for the following stud attachments: the Nobel Biocare Standard Ball, Nobel Biocare 2.25-mm-diameter ball, Zest Anchor, Zest Anchor Advanced Generation, and Sterngold ERA white and orange attachment systems when subjected to dislodging forces in vertical, oblique, and anterior-posterior directions.

For this resistance to separation, the peak load is important clinically. It tells the clinician how much retentive force occurs within the overdenture attachments before the attachment completely separates from its components. Based on the present study, the clinician may be able to make empirical decisions on attachment selection, depending on the amount of retention desired and the specific clinical situation.

The ZAAG attachment may be used when a high degree of retention is desired. In cases of severely resorbed mandibles, the Nobel Biocare standard ball, Nobel Biocare 2.25-mm-diameter ball, and ZAAG may be used when a high degree of stability is desired for the overdenture. A clinical situation in which an attachment of lesser retention may be desirable is the patient with dexterity problems who may have difficulty inserting and removing the overdenture. For these cases, the Sterngold white and the Zest anchor may be more appropriate.

Of equal importance to retention is the amount of wear that occurs as these attachments are functioning. Something with a high peak load may quickly lose its maximum resistance to dislodgment, need frequent replacement, and cause unfavorable stresses to the implants. A future study examining the wear of these attachments and how they correlate with stress distribution would contribute to the body of knowledge associated with these implant-related studies.

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