Effect of Implant Angulation upon Retention of Overdenture Attachments

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***Introduction*: Overdentures supported and retained by endosteal implants depend upon mechanical components to provide retention. Ball attachments are frequently described because of simplicity and low cost, but retentive capacity of these components may be altered by a lack of implant parallelism.**

***Purpose*: The aim of this *in vitro* study was to investigate the retention of gold and titanium overdenture attachments when placed on ball abutments positioned off-axis.**

***Methods and Materials*: Four ball abutments were hand-tightened onto ITI dental implants and placed in an aluminum fixture that allowed positioning of the implants at 0°, 10°, 20°, and 30° from a vertical reference axis. Gold and titanium matrices were then coupled to the ball abutments at various angles and then subjected to pull tests at a rate of 2 mm/second; the peak loads of release (maximum dislodging forces) were recorded and subjected to statistical analyses. A balanced and randomized factorial experimental design testing procedure was implemented.**

***Results*: Statistically significant differences in retention of gold matrices were noted when ball abutments were positioned at 20° and 30°, but not at 0° and 10°. Statistically significant differences were noted among the titanium matrices employed for the testing procedure, as well as for the 4 ball abutments tested. Angle was not a factor affecting retention for titanium matrices.**

***Conclusions*: (1) The gold matrices employed for the testing procedures exhibited consistent values in retention compared to titanium matrices, which exhibited large variability in retention. (2) Angle had an effect upon the retention of gold matrices, but not for titanium matrices.**

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INDEX WORDS: implant overdenture, parallelism, ball abutment, gold matrix, titanium matrix

TREATMENT OF the edentulous patient with implant-stabilized removable prostheses has been shown to provide a predictable and successful outcome that overcomes the functional deficiencies once associated with traditional complete dentures.[1] The functional benefits of complete dentures, supported and retained by a few roots, have been clinically documented. It was natural, therefore, to adapt the osseointegration method to the overdenture concept in patients who could accept wearing removable dentures.[2]

Prostheses supported by both implants and mucosa generally require fewer implants than do totally implant-supported fixed prostheses, and as such offer patients an economic alternative.[3] Two dental implants are usually considered the minimum number necessary for mandibular implant overdenture treatment, allowing the mucosa and implants to help provide support, retention, and stability for the prosthesis;[4] however, in 1997, Cordioli et al reported that even a single implant placed in the mandibular midline of the extremely resorbed mandible may substantially improve retention and stability of a denture.[5] The implant-retained overdenture helps provide the patient

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with a stable and retentive prosthesis, and with confidence that the prosthesis will not become dislodged when speaking or eating.

Clinicians have stated that implants planned for use with overdentures must be parallel to one another to obtain predictable attachment retention and complete seating of the retentive elements and to prevent premature wear or fatigue of the involved components.[6-11] It has also been suggested that implants be positioned parallel to the path of insertion of planned prostheses and as perpendicular to the occlusal plane as possible so that they are loaded axially, minimizing the production of bending moments.[12] Some investigators believe that nonparallel implants could impede passive insertion of the prosthesis and lead to premature wear of ball or stud-type prosthetic components. This supposition is further reinforced by the literature provided by implant manufacturers.[9,13] It has been suggested that although divergence of about 10° between 2 unsplinted implants can usually be tolerated, excessive wear will result from wide divergences or convergences, leading to a decrease in retention of the implant overdenture components.[14]

It has been reported that there is less need for parallelism of implant abutments used with magnet-retained overdentures because the line of insertion is less critical,[15] but few authors have considered that comparable advantages might accrue with ball attachments as well. Many clinicians assume that ball attachments cannot be used when implant placement is not parallel, and they will attempt to use angled abutments, flexible attachments, and bar/clip assemblies to compensate in such situations.[16-19] Not only does the employment of these modalities increase the complexity of treatment, but it also likely increases cost to the patient and practitioner. Mericske-Stern and Zarb contend that although the use of retentive ball abutments and magnets is the easiest and most cost-effective way to retain dentures by implants, they do not believe that ball abutments may be used to compensate for unfavorable and nonparallel alignment of implants without severely compromising retention of the definitive prosthesis.[18]

The purpose of this *in vitro* investigation was to evaluate the retentive capacity of gold and titanium overdenture attachments placed on implants positioned at 0°, 10°, 20°, and 30° from a vertical reference axis.

Materials and Methods

Four standard spherical ball abutments were obtained from a dental implant manufacturer (Institut Straumann AG, Waldenburg, Switzerland). Ball abutments were randomly measured in various directions prior to use with the aid of a micrometer to ensure that there was no greater deviation in diameter than as stated by the manufacturer.

The 5 measured ball abutments then were hand-tightened onto 4 4.1-mm diameter ITI dental implants (Institut Straumann AG) with the use of a ball abutment driver. The implant threads were coated with Loctite Threadlocker® epoxy resin adhesive (Permatex, Hartford, CT) and then threaded into 4 premachined 3.8-mm diameter holes in a cylindrical aluminum rod. Each implant within the aluminum rod was equally spaced and paralleled to one another with the use of a dental surveyor. The aluminum rod was held within a rectangular sleeve that allowed rotational positioning of the implants at 0°, 10°, 20°, and 30° with respect to a vertical reference axis (Fig 1). The implant "jig" was then fastened to a miniature vise mounted on a rectangular aluminum platform that could be securely clamped to a plate attached to a 500 N force transducer.

Four gold and titanium matrices were obtained from the manufacturer (Cendres & Metaux, Bienne, Switzerland) and encased in custom-fabricated aluminum jigs with acrylic resin, PMMA (Motloid Corp., Chicago, IL). Modifications to the matrix jigs were made so that they could be loosely or rigidly suspended from the actuator

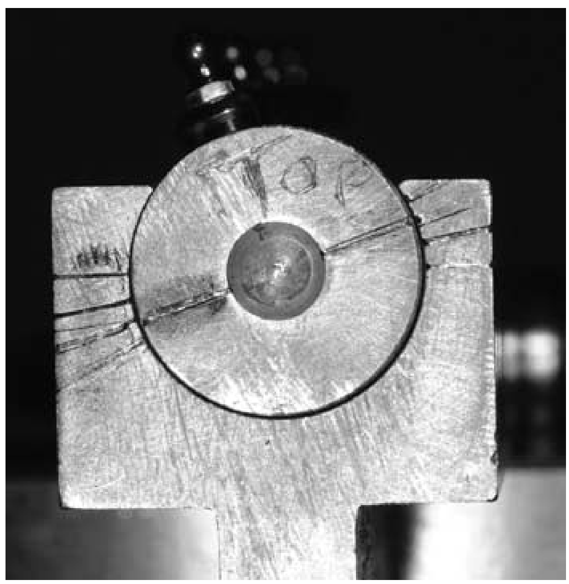

Figure 1. Implant jig positioned at 20°.

arm of a Mini Bionix II MTS 858 machine (MTS Corp., Eden Prairie, MN). For testing procedures at 0°, the gold and titanium matrix jigs with their respective gold or titanium matrix were rigidly fixed on the actuator arm and then passively placed onto the ball abutment. Once coupled, the matrix jig was loosened and the testing procedure commenced. This ensured that no adverse lateral forces were placed on the ball abutment upon removal of the matrix. Matrix jigs that were tested at 10°, 20°, and 30° were first rigidly fixed on the actuator arm, coupled with a ball abutment, and then loosened to again ensure that lateral forces would not disrupt removal of the gold or titanium matrix once pull testing commenced.

Dislodging tensile tests of the gold and titanium matrices were executed at 2 mm/second, simulating the approximate rate at which a patient would remove an implant-retained removable prosthesis (Fig 2). These pull tests yielded the peak retentive load, or maximum dislodging force, measured in Newtons, as well as load–displacement curves.

A balanced and randomized factorial experimental design testing procedure was implemented using the factors "ball," "matrix," and "angle" (Design-Expert 6.06, Stat-Ease, Inc., Minneapolis, MN). Each factor had 4 variables: *Factor* 1: ball abutment (#s 1, 2, 3, and 4); *Factor* 2: matrix (#s 1, 2, 3, and 4); *Factor* 3: angle (0°, 10°, 20°, 30°). Therefore, 64 different permutations of ball abutments, matrices, and angles could be produced. For statistical analysis, both "ball" and "matrix" were treated as categorical variables, and "angle" as a continuous variable. Pull tests were performed in an order randomized by the design software for both gold and titanium matrices.

One ball abutment and gold matrix pair was randomly selected and subjected to 10 additional pulls at 0°, 10°, 20°, and 30° to further validate the findings from the factorial analysis design testing procedure.

The null hypotheses assumed for the testing procedures were that no difference in retention of gold and titanium matrix overdenture attachments exists when ball abutments are positioned at 0°, 10°, 20°, and 30° from a vertical reference axis.

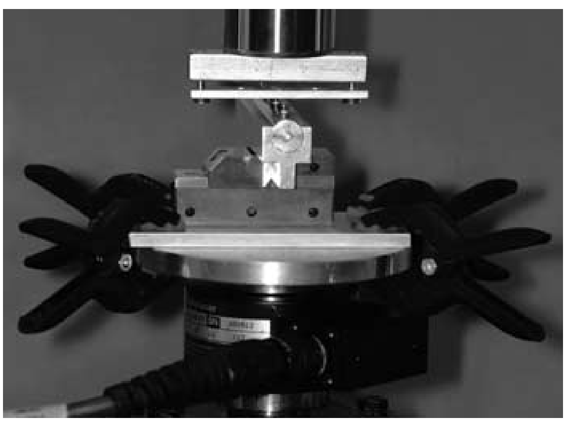

Figure 2. Test apparatus prior to application of dislodging forces.

Statistical Methods

ANOVA and a 95% Tukey *post hoc* test were applied to compare diameter measurements of the 4 ball abutments (SPSS 10.1 for Windows, SPSS, Inc., Chicago, IL). The factorial peak retention data obtained from gold and titanium matrix testing were analyzed within Design-Expert using ANOVA routines.

Results

Ball Abutment Diameters

A statistically significant difference was noted among the 4 ball abutments ($p \leq 0.02$); however, the largest difference among the mean diameters was only 3 μm. No statistically significant differences in diameter measurements were noted within each ball abutment.

Gold Matrix Data

It was concluded that for the gold matrices all factors ("ball," "matrix," and "angle") were statistically significant in determining retention ($p \leq 0.001$). An overall mean retention value of 23.8 ± 2.2 N was calculated for the 64 ball abutment-angle-matrix combinations tested. Design-Expert was further utilized to calculate means and standard deviations for the ball abutment-angle-matrix combinations examined. These calculations determined that ball abutment #2 exhibited the highest mean retention value (26.6 ± 2.9 N; $p < 0.001$) and ball abutment #4, the lowest (21.8 ± 3.7 N; $p < 0.001$) over the combination of all ball abutments, angles, and matrices. Gold matrix #4 displayed the highest mean retention value (24.8 ± 3.3 N; $p < 0.001$) over the 4 ball abutments and angles tested. Ball abutments and matrices positioned at 0° displayed the highest mean retention value (26.7 ± 2.9 N; $p < 0.001$), while those positioned at 30° exhibited the lowest mean retention value (21.4 ± 3.9 N; $p < 0.001$).

Using all of the retention data, a mathematical model was developed within Design-Expert that was predictive of the experimental values for all ball abutment-matrix-angle combinations tested (ANOVA; $p \leq 0.0001$). Linear regression analysis (SPSS) of the predicted values versus measured retention determined that approximately 66% of the variability in the predicted retention values generated by the optimization model could be directly obtained from actual retention data ($r^2 = 0.66$; $p \leq 0.0001$). This model could then be used to provide additional insight into component selection (beyond those actually tested) for the purpose of either optimizing or minimizing retention. For example, it was determined that optimal retention could be obtained with ball abutment #2 and gold matrix #4 at 0° (31.2 N). Maximum and minimum retention values at each angle, calculated from the mathematical model, ranged from (Fig 3): 31.2 to 21.6 N (0°); 27.9 to 19.8 N (10°); 27.6 to 18.4 N (20°); and 25.8 to 15.2 N (30°).

From the data obtained by the factorial experimental design, it was clear that the angle at which ball abutments were positioned had an effect upon the retention of gold matrices. To validate this finding, a single ball abutment and gold matrix combination was chosen (removing those variables) for pull tests at 0°, 10°, 20°, and 30°. A statistically significant difference was noted when the ball abutment was positioned at 20° and 30°, but not between 0° and 10° (ANOVA; 95% Tukey).

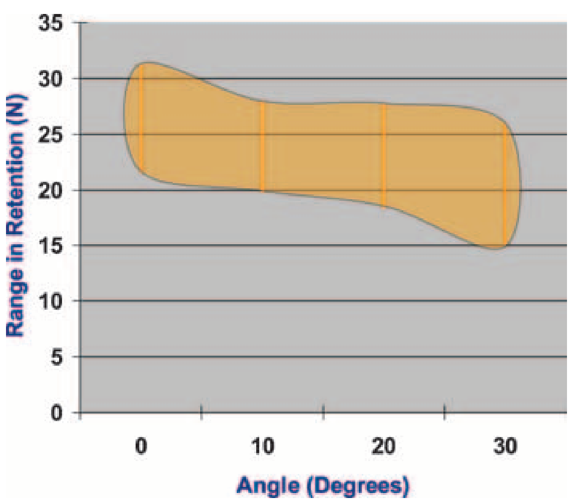

Figure 3. Range in retention of gold matrices (predicted values).

Titanium Matrix Data

The factorial peak retention data obtained from titanium matrix testing were analyzed within Design-Expert using ANOVA routines. For this implant component, it was concluded that only "ball abutment" and "matrix" were statistically significant in determining retention ($p \leq 0.001$). An overall mean retention value of 19.4 ± 4.7 N was calculated for the 64 ball abutment-angle-matrix combinations. Design-Expert was used to calculate means and standard deviations for the ball abutment-angle-matrix combinations examined. These calculations determined that ball abutment #2 exhibited the highest mean retention value (23.0 ± 11.7 N; $p < 0.001$) and ball abutment #3, the lowest (17.2 ± 4.6 N; $p < 0.001$) over the combination of all balls, angles, and matrices. Titanium matrix #2 displayed the highest mean retention value (28.9 ± 6.3 N; $p < 0.001$) over the ball abutments and angles tested. For all ball abutments and matrices tested, those that were positioned at 0° displayed the highest mean retention value (20.6 ± 8.0 N; $p < 0.001$), while ball abutments at 30° exhibited the lowest mean retention value (18.3 ± 9.6 N; $p < 0.001$).

Using the retention data for the titanium matrices, another mathematical model predictive of the experimental values for all ball-matrix-angle combinations tested (ANOVA; $p \leq 0.0001$) was developed within Design-Expert. Linear regression analysis (SPSS) of the predicted values versus measured retention determined that approximately 66% of the variability in the predicted retention values generated by the optimization model could be obtained from actual retention data ($r^2 = 0.66$; $p < 0.0001$). The model generated concluded that optimal retention could be obtained with ball abutment #2 at 0° with titanium matrix #2 (39.6 N). Retention values for this implant attachment ranged from 39.6 to 11.8 N (0°), 36.6 to 10.3 N (10°), 34.8 to 11.2 N (20°), and 32.6 to 9.2 N (30°) (Fig 4).

Load–Displacement Curves

Load–displacement curves were recorded during each pull test. These curves displayed the engagement and release characteristics as well as the timing of the peak retention load. Consistency in gold matrix load–displacement curves was noted

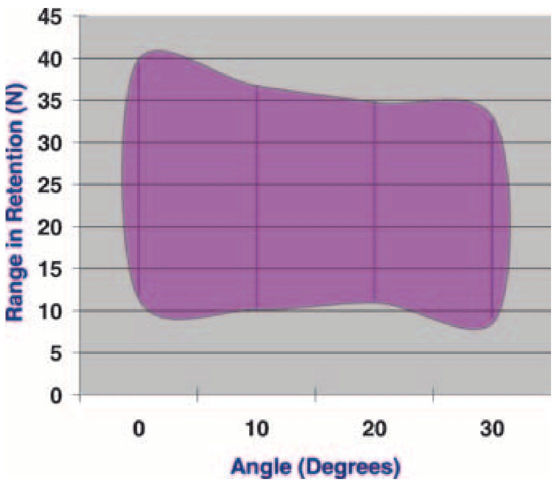

Figure 4. Range in retention of titanium matrices (predicted values).

among ball abutments positioned at 0°, 10°, 20°, and 30° (Fig 5). Titanium matrices exhibited extremely inconsistent load–displacement curves regardless of ball abutment angulation (Fig 6).

Discussion

The ball-retained overdenture has been proven to be an effective and simple treatment for the edentulous patient treated with endosteal dental implants.[20,21] There are numerous studies documenting patient satisfaction with overdentures retained by dental implants,[4,22,23-26] and the incorporation of dental implants into the edentulous treatment plan is considered the baseline standard of care, especially for the mandibular edentulous patient. In 2002, the *McGill Consensus Statement on Overdentures* asserted that mandibular 2-implant overdentures have been shown not only to be superior to conventional complete dentures, but also to improve the quality of life for these patients regardless of the attachment system used (bar, ball, magnet).[27] This consensus also found that the implant overdenture prosthesis is significantly more stable than a conventional denture prosthesis, enabling the edentate patient to chew various foods more effortlessly.

In an earlier publication involving ball-retained overdentures, Donatsky found the ball-retained overdenture to be a successful alternative to the combined lingual-vestibuloplasty/free split-thickness skin graft technique.[28] In comparison to the bar-retained overdenture, a study by Naert et al found that significantly higher retention values were observed with bar-retained overdentures than with ball-retained overdentures; however,

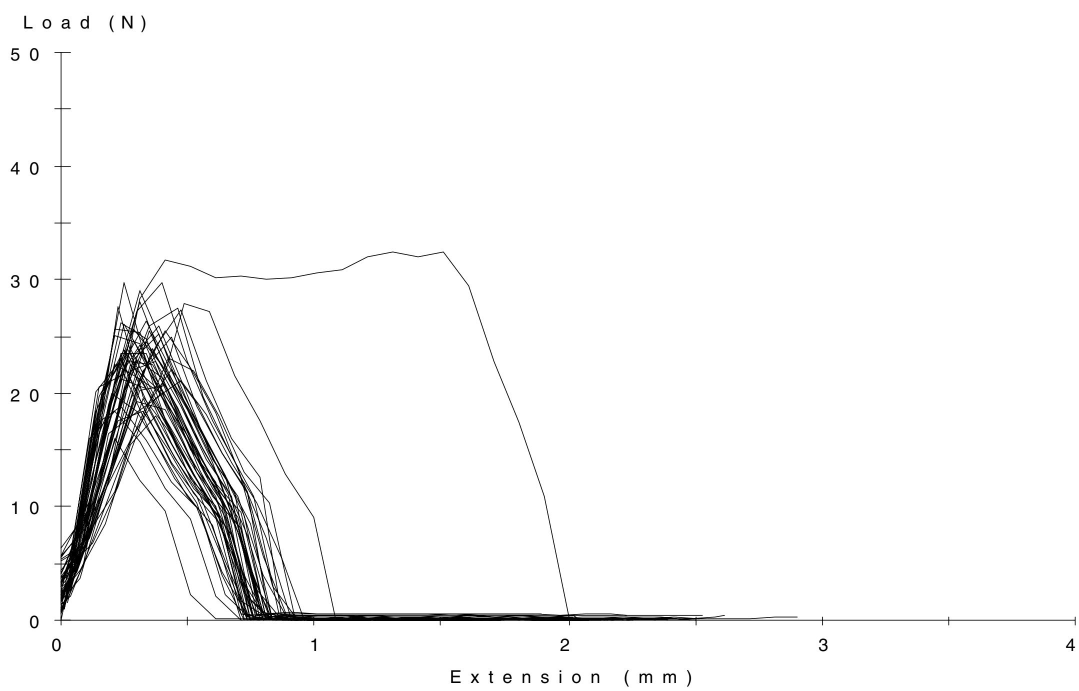

Figure 5. Load–displacement curves for gold matrices.

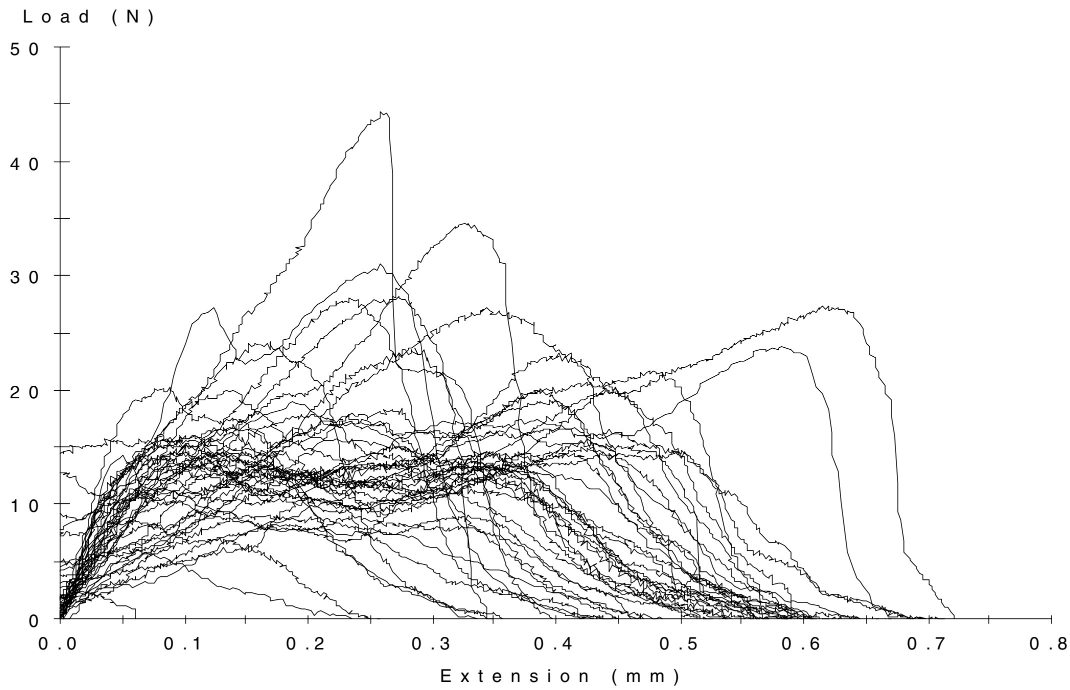

Figure 6. Load–displacement curves for titanium matrices.

assessment of patient satisfaction did not reflect this difference.[29] In a comparative 5-year study by Gotfredsen and Holm, periimplant conditions and maintenance requirements for implant-supported overdentures were evaluated. These authors found a 100% survival rate for 2-implant ball- or bar-retained overdentures.[30] No differences in marginal bone loss or health of the periimplant mucosa were observed, but the frequency of technical complications and repairs per patient was higher for bar attachments than ball attachments. Yusuf and Ratra have corroborated the high success rates associated with ball-retained overdentures when AstraTech dental implants were placed in the parasymphyseal region of 25 adult patients. After an average period of 4 years and 2 months, success rates for osseointegration and prosthesis function approached 94%, with minor complications reported.[31] These data indicate that implant-retained overdenture treatment should not be considered a second-class treatment; rather, it may be the therapy of choice.[22,32,33]

To date, there is no literature reporting the retentive capacity of gold and titanium matrices when placed on ball abutments positioned at 0°, 10°, 20°, and 30° from a vertical reference axis. The importance of such information is overshadowed by the large number of manufactured overdenture attachments available for dental implant systems compensating for nonparallel implant placement. Although the ball abutment with its gold or titanium matrix is a relatively straightforward treatment modality, it is frequently not considered a viable solution when dental implants are not positioned parallel to one another. When more than 1 dental implant is considered for overdenture treatment, it is important that the gold or titanium matrices be parallel to one another, and not necessarily parallel to the long axis of the dental implant. Detractors of the ball anchor method fail to emphasize the importance of the position of the retentive gold or titanium matrix relative to the ball abutment, and that this position dictates predictable retention depending on the matrix attachment employed.

In a preliminary investigation by Wiemeyer et al,[11] it was determined that ball abutments on dental implants may be divergent up to 60° from one another without compromising the seating of a prosthesis when gold matrices are used parallel to one another. While conceptually valid, this study did not investigate the *retentive capacity* of the gold matrices employed when implants were positioned in a nonparallel fashion, and that implants placed off-axis may compromise retention.

This present study provides an initial investigation into the retentiveness of gold and titanium overdenture attachments provided by a single dental implant attachment manufacturer. Although the results of this study confirm that there is a 25% decrease in retention of gold matrices when implants are positioned at 30° (compared with implants positioned at 0°), the reduction in retention may not be so clinically significant to warrant utilization of a more expensive and complicated implant overdenture attachment system. In addition to angle being a significant factor in determining retention of gold matrices, the specific ball abutment and gold matrix tested also determined retention values. It is probable that the small differences found in ball abutment diameters do not significantly contribute to retention when applied to the clinical situation, and it is rather the random combination of the gold matrix chosen with its corresponding ball abutment that dictates retention values.

Overall, gold matrices provided relatively consistent retention values and very similar load–displacement behavior compared to the titanium matrices tested. The simple lamellar retentive-design feature of the gold matrix attachment (Fig 7) may be more inherently reliable or predictably manufactured because of its single-component design compared to the titanium matrix.

The large range in retention seen with the titanium matrices was unexpected. The manufacturer of this attachment suggests that this attachment will provide a defined retention force of 7–11 N,[9] while the range found in this study was 9.2–39.6 N. A significant degree of variation in retentiveness was seen among the 4 titanium matrices used and within a single titanium matrix as well. Although the results of this investigation suggest a 3-fold increase in retention of titanium matrices than as stated by the manufacturer, the large variation in retention may be explained based on design characteristics of the titanium matrix. The retentive element of this type of attachment is in the form of a C-shaped stainless steel spring (Fig 7). It is possible that the variation in retention of these matrices may come from the positional configuration of the opening in the C-shaped spring, and where that opening lies when the matrix is removed from the ball abutment. Upon close inspection of the titanium matrix, it was noted that this spring exhibits significant lateral movement within the lower housing of the matrix. This movement may continuously alter the position of the opening within the spring prior to tensile load application as well as introduce possible contributions from binding or frictional forces. Close examination of the load–displacement curves validates that the spring exhibits some "float" during initial tensile withdrawal force application. This assumption is reinforced by the amount of "noise" seen within each load–displacement curve during the application of tensile withdrawal forces.

Figure 7. Titanium matrix (unassembled, with C-shaped, stainless steel spring).

Conclusions

The following conclusions were made:

1. Gold matrices demonstrated a smaller range in retention values (i.e., higher consistency) over all ball abutment-matrix-angle combinations compared to titanium matrices (Fig 8).

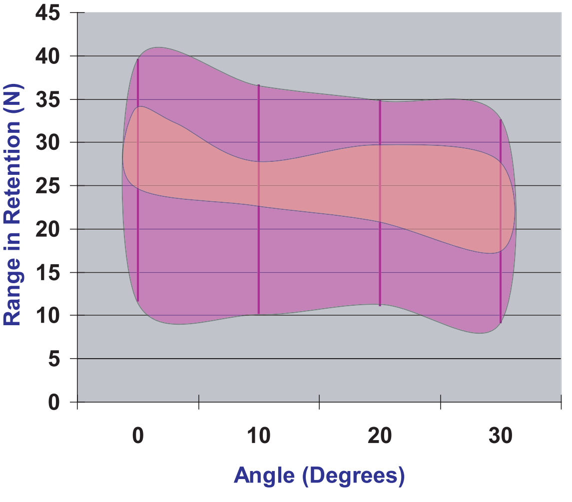

Figure 8. Comparison of retention value ranges (*Orange*, gold; *Purple*, titanium).

2. Ball abutment, angle, and matrix were significant factors contributing to the retention values obtained for gold matrices.
3. The ball abutment and matrix employed in titanium matrix testing were significant factors in determining retention.
4. The optimization models produced allow for selection of components to maximize or minimize retention of gold and titanium matrices. These models also provided insight into the range in retention values to be expected with varying combinations of ball abutment, matrix, and angle.

Although further investigation is necessary, this study suggests that if 2 ball abutments are employed in overdenture treatment, they may each be up to 30° off-axis and successfully retain an overdenture. As long as gold matrices are used and the matrices are paralleled to one another, practitioners may be comfortable implementing this treatment modality.

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