Resistance to Wear of Four Matrices with Ball Attachments for Implant Overdentures: A Fatigue Study

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Keywords
Fatigue study; ball attachment; overdenture; dental implants; retention; implant-retained overdenture; Teflon; titanium; gold; O-ring; wear.

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Abstract

Purpose: The study evaluated in vitro the retention force and the wear resistance over simulated function of four matrix components of ball attachments for implant-retained overdentures.

Materials and Methods: Four types of matrices for ball attachments were evaluated in a fatigue study simulating 5500 cycles of insertion and removal. The matrices used were (1) a Teflon matrix supported by a metal housing, (2) a titanium matrix, (3) a gold alloy matrix, (4) an O-ring matrix using the red color ring for medium retention. Dimensional changes of the ball attachments were investigated with a profilometer.

Results: The Teflon matrices showed an increase of 27% in retention at 5500 cycles while the gold alloy matrices showed an increase of 50% in retention in the first 500 cycles and remained relatively stable up to 5500 cycles. On the other hand, titanium matrices and O-ring matrices exhibited progressive loss of retention ending with 68% and 75% of retention loss, respectively, at 5500 cycles. Dimensional analysis by profilometer revealed significant wear on the ball attachment only for titanium matrixes.

Conclusions: Gold alloy and Teflon matrices showed the highest retention values without retention loss after 3 years of simulated function. Titanium and O-ring matrices presented a continuous loss of retention with the highest wear on the ball attachments when combined with the titanium matrix.

Implant overdentures are a well-established therapeutic option for edentulous patients to obtain improved retention and stability over traditional complete dentures. The most common types of retention systems are bars with clips inserted in the removable prosthesis and ball attachments screwed on dental implants with matrices inserted into the prosthesis. A wide range of attachment designs is available through multiple implant manufacturers, but little data are provided on the retention value and the longevity of such parts.

In the dental literature, similarities and differences of commonly used attachment systems have been discussed in relation to load transfer to implants and bone,[1,2] patient satisfaction,[3,4] and retention and wear resistance over time.[5-7] In relation to bone loss around implants, no significant differences have been demonstrated between ball- or bar-retained overdentures.[8] In regards to patient satisfaction relating to function and cleansability, no differences have been demonstrated when comparing the two prosthetic alternatives.[9]

When retention was investigated for ball attachments, authors have found that different attachment systems provide varying degrees of resiliency, both in horizontal and vertical directions with varying degrees of wear over time.[6,10-14] It has also been demonstrated that most attachment systems suffer from wear during insertion and removal as well as under functional load.[7,11,13,15] In a study by Walton and Ruse,[7] metal bars exhibited a loss of retention of 10% to 20% in metal and plastic clips after 5500 cycles. On the other hand, when Breeding et al[15] applied a load on the saddles of the prosthesis rather than on the attachment itself, they failed to show significant variations of retentive forces even after 345,600 cycles.

According to Lehmann and Arnim,[16] attachment retention forces from 5 to 7 N should be sufficient to stabilize overdentures in function; however, a clinical study on patient satisfaction found that patients have a strong preference for more retentive attachments.[17,18] Therefore, retentive force and loss of retention over time are important parameters in the selection of an attachment system.

Table 1 Materials used

Attachment component	Material	Lot number	Quantity
Spherical attachment	Titanium type 5	609,564.078	20
Holders for Teflon matrix	Stainless steel	609,431.029	5
Teflon matrix	Teflon	609,751.027	5
Titanium matrix	Titanium type 5	609,755.031	5
Noble alloy matrix	Noble alloy (Au 60%, Pt 24%, Pd 15%, Ir 1%)	609,431.012	5
O-ring kit	Natural rubber	609,429.047	5

Manufacturer: Sweden & Martina, Padova, Italy.

Bar attachments, rather than ball attachments, have been recommended when restoring implants that have a divergence of more than 10°; however, from a maintenance standpoint, the type of attachment was not found to influence prosthetic complications.[19] In an in vitro experiment, Gulizio et al[20] found that retention of a noble alloy matrix ball attachment system was compromised by implant angulation, but was not compromised in the case of titanium matrices. A recent fatigue study showed acceptable retention values over time for spherical attachments when tested with different implant and matrix angulation.[21] Other authors have compared retention of attachments when removing overdentures in the path of insertion and in oblique directions and were unable to detect significant differences with the different attachment systems.[22,23] In recent years, ball attachments have gained popularity over bars, as they are easier to manage in limited prosthetic space, more economical, easily cleansable, and less technique sensitive.[24]

The purpose of the present study was to evaluate the retention force and the resistance to wear of four matrix components with ball attachments after simulated insertions and removals, and to evaluate the wear of ball patrix.

Materials and methods

Specimen preparation

Four types of ball attachment matrices were evaluated: a Teflon matrix (Sweden & Martina, Padova, Italy) supported by a metal housing, a titanium matrix (Sweden & Martina), a noble alloy matrix (Sweden & Martina), and an O-ring matrix (Sweden & Martina) using the medium retention ring (Table 1, Fig 1). All matrices were tested on the same type of ball patrix (Spherical attachment, Sweden & Martina) measuring 2.20 mm in diameter and 4 mm in height. Ball patrix was screwed on a dental implant of 3.80-mm diameter (Khono, Sweden & Martina).

All four types of matrices were tested using five specimens for each type for a total of 20 specimens. Every specimen underwent 5500 cycles of insertion and removal, corresponding to approximately 3 years of function, assuming the prosthesis would undergo five insertions and removals daily.

Mechanical testing

The specimen holders consisted of two cylindrical metal housings (19-mm diameter, 80-mm height) each having an internal housing of 15-mm diameter and 12-mm depth. These internal housings provided undercuts for retention of the fixation resin. Using a surveyor (Ney Dental Inc., Bloomfield, IL), the implants were positioned at a 90° angle to the base of one of the two specimen holders, and secured by cold-curing acrylic resin (Pi Ku-Plast, Bredent, Senden, Germany), added at incremental doses to minimize setting distortion. A ball patrix was screwed on the implant and tightened at a torque of 20 N·cm using a torque-controller device (3i Implant Innovations, Palm Beach, FL). The holder with the complex implant-ball patrix was positioned on the upper arm of an MTS 810 testing machine (Material Testing System, Minneapolis, MN), equipped with a loading cell with a maximum capacity of 2000 N (Vishay,

Figure 1 Ball attachment and different matrices.

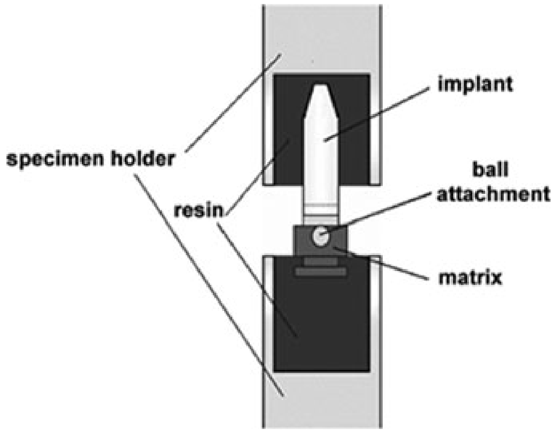

Figure 2 Specimen assembly mounted on the testing machine.

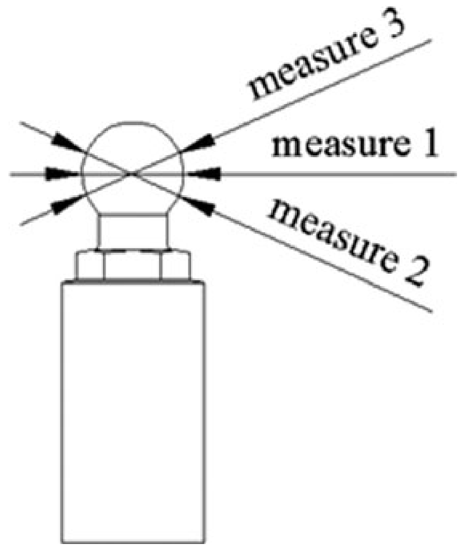

Figure 3 Diagram of measured diameters. Diameter 1 (90°), diameter 2 (+24°), and diameter 3 (−24°).

Tedea Huntleigh, model 616, Shelton, CT). A new ball patrix was positioned on the holder for every matrix specimen tested.

To guarantee a correct alignment of the two components in the horizontal plane, the matrices were first carefully oriented on the patrix, and the lower arm of the testing machine was then raised to the correct position with the already mounted holding device. Again, cold-curing acrylic was used to secure the matrix to the holding device (Pi Ku-Plast) (Fig 2).

Each specimen was fatigue tested by seating and separating the components for 5500 cycles, at a rate of 12 cycles/min, with a crosshead speed of 5.4 cm/min, and a distance of 2.25 mm separating the components. For each cycle, tensile and compressive measurements were recorded.

To detect any anomalies of movement or changes in the surface of ball attachments, every test was video recorded by a camcorder (Keyence VH5901 Advanced Micro Devices, Inc., Sunnyvale, CA). The camcorder delivered magnified views of the specimens during testing, facilitating instantaneous detection of visible movements of components embedded in acrylic resin.

Dimensional analysis

Dimensional changes of the ball patrices were investigated using a profilometer (Nikon Profile Projector V-12, Nippon Kogaku, Tokyo, Japan). All new ball patrices were measured before testing. One specimen in each group was randomly selected and observed at a magnification of 100× before and after fatigue testing. Ball patrices previously oriented on a true vertical direction by use of a surveyor were maintained in the specimen holder during dimensional analysis to guarantee correct orientation. Measurements of the diameter of the ball were taken at three angles: the first diameter at a 90° angle to the major axis of the ball patrix, and the other two at a 24° angle to the major axis on both sides (Fig 3).

Statistical analysis

Normality of the data distribution and homogeneity of variances in the groups were first verified using the Kolmogorov-Smirnov test and the Levene test. Then, a one-way analysis of variance (ANOVA) statistical analysis was applied every 500 cycles to verify if the group differences were statistically significant. The Tukey's test was applied for post-hoc comparisons. In all tests, the level of significance was set at $p < 0.05$. Whenever normality test failed Kruskal-Wallis one-way ANOVA was used.

Results

The fatigue cycles for each group are reported in Figure 4. First, the curve shows a peak corresponding to the force needed to separate the components; it is then followed by a flat curve at level 0 corresponding to the time when the components are separated, and ends with a symmetric negative peak when the matrices are reinserted. After fatigue testing, a modification of symmetry of the curve and a shift of maximum peak with the increasing number of cycles were observed.

Retention values at different time cycles are reported in Table 2. Statistical analysis revealed that all groups presented significant differences in retention loss with an increasing number of cycles ($p < 0.05$).

The noble alloy group showed consistent high retention values. In the first 250 cycles, retention values increased by 50%, and continued to increase slowly up to 5500 cycles. Teflon matrices also showed a progressive increase in retention up to 2500 cycles, followed by a slow loss of retention. At 5500 cycles, the measured retention was still 27% higher than baseline. The titanium group exhibited loss of retention over time, ending with a retentive value at 32% of its baseline value (Fig 5). The O-ring group showed the lowest baseline retentive force, with a rapid decrease in retention values over time. Most of the retention loss occurred in the first 1500 cycles, ending with a value corresponding to 25% of its initial retention.

Dimensional analysis of components is reported in Table 3. Significant dimensional changes of the ball patrices were observed only in the titanium group. The data were confirmed by the large variation in the curve after 5500 cycles, both in terms of symmetry of the peaks, and in shift of maximum peak position on the time axis (Fig 4).

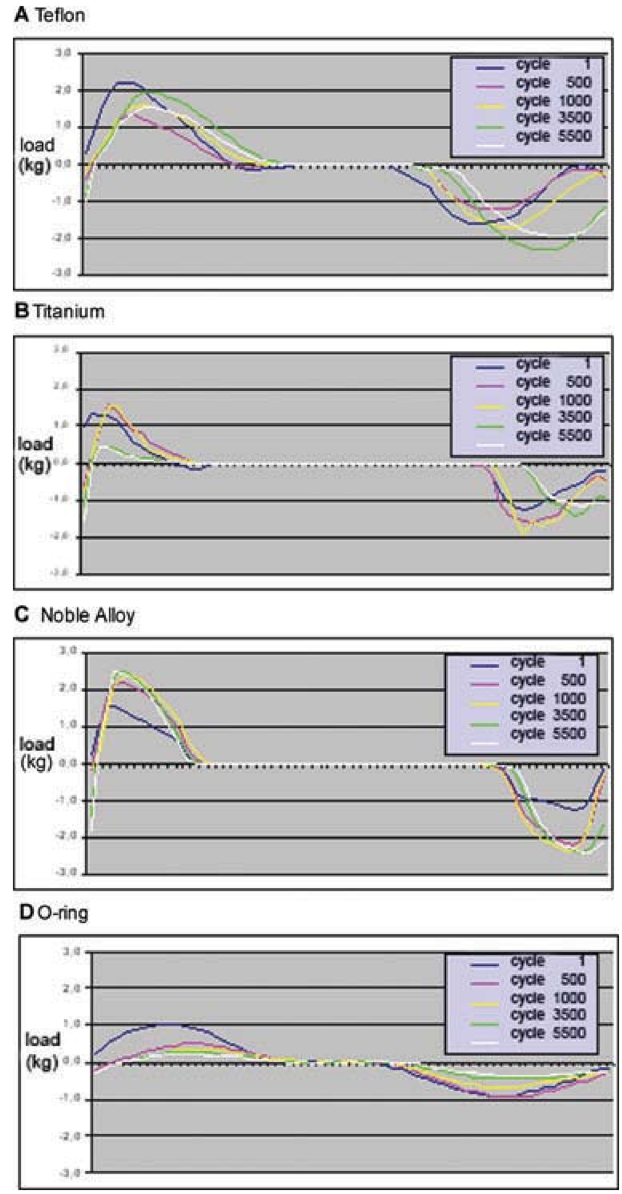

Figure 4 (A)-(D) Retention curves at different time cycles.

Table 2 Average retention values (kgf)

Cycle #	O-ring	Teflon	Titanium	Noble alloy
1	1.04	1.42	1.35	1.56
500	0.42	1.47	1.94	2.36
1000	0.36	1.66	1.57	2.42
1500	0.33	1.90	1.25	2.43
2000	0.32	2.30	1.05	2.44
2500	0.29	2.35	0.95	2.47
3000	0.29	2.18	0.71	2.47
3500	0.29	2.13	0.50	2.47
4000	0.28	2.01	0.47	2.50
4500	0.27	1.99	0.48	2.50
5000	0.26	1.91	0.43	2.50
5500	0.25	1.81	0.44	2.49

Discussion

Although no data regarding the specific attachment systems tested in the present study could be found in the literature, a comparison could be done with studies on similar ball attachment systems used on natural teeth or dental implants. The main technical features of these attachments are the geometry of engaging parts and the materials of both matrix and attachment; all these aspects should be considered when comparing attachment systems.

In the present study, noble alloy matrices showed an important increase in retention values in the first 250 cycles. At the end of 5500 cycles, retention values were still higher than baseline and the highest among the four groups of the present investigation. This finding, even if in contrast with clinical experience, is in agreement with findings by Besimo and Guarneri[12] and Setz et al[14] where attachments of similar geometry and noble alloy matrices were used. A possible explanation could be related to geometrical adaptation (plastic strain) of the matrix that contributes to an increase of interferences in the coupling of components, and consequently, to an increase in retention. This is justified by the lower yield stress of noble alloy compared to titanium. On the contrary, Doukas et al[25] found a significant decrease in retention, varying form 32% to 50% according to different interimplant distance, in ball attachments with noble alloy matrix and titanium ball patrix, after 6 months of repeated manual removals. Differences from our results could be due to differences in matrix geometry and study methodologies. Depositions of gold particles on the ball patrices were observed in this group. These deposits could be attributed to the difference in hardness between titanium and noble alloy.[26]

Teflon matrices also showed a gradual increase of retention values from baseline up to 2200 cycles. After 2200 cycles, once geometry had become stable, wear effects became visible with a decrease of retention values. Teflon is a material with auto-lubricating properties contributing to a low level of wear. Therefore, all changes in retention are more gradual when compared to other materials with a higher frictional coefficient. Our results differed from other studies[10,11] where a significant decrease in retention was found for plastic matrices (ERA,

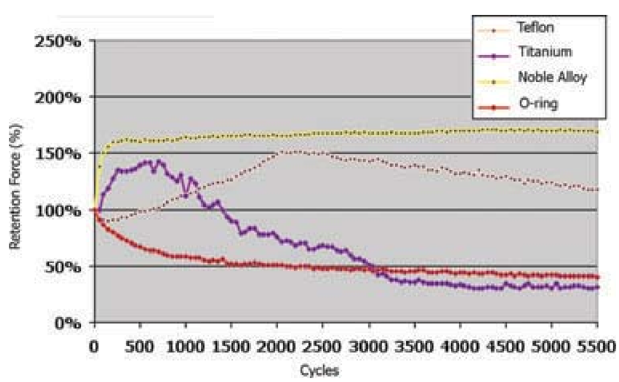

Figure 5 Average loss in retention (%) over 5500 cycles.

Table 3 Ball patrix diameters (mm) before and after 5500 cycles of insertion/removal of each type of matrix

	Diameter 1	Diameter 2	Diameter 3
New ball patrix	2.238	2.223	2.225
Ball patrix (Teflon)	2.237	2.221	2.215
Ball patrix (titanium)	2.180	2.243	2.237
Ball patrix (noble alloy)	2.237	2.224	2.227
Ball patrix (O-ring)	2.237	2.220	2.220

ZAAG, Access p-post, Flexi OD). Contradictory results could be due to different plastic materials and different geometries of attachments employed.

Titanium matrices, after an initial increase of retention values, showed a progressive loss of retention. When examining ball patrix geometry, these attachments showed extensive wear to the point of becoming almost conical in the contact area. This geometrical change is well documented by our dimensional analysis. In the first 2550 cycles, wear seemed to be dominant, and led to a progressive decrease in retention. Wear and loss of retention can be attributed to the contact of two metallic surfaces with the same hardness. Wear produces a rapid diminution of geometrical interferences between parts, and consequently, a rapid and progressive loss of retention. A reduction of interferences also determines a diminution in contact force between components with a consequent decrease in wear in the last 3000 cycles. A metal-to-metal contact can also be found in the noble alloy matrix; however, the behavior in the two types of matrices is quite different, due to their differences in macro-geometry. In fact, the noble alloy matrices were cylindrical but with discontinuities that diminished considerably the overall stiffness of the structure. The tested titanium matrices were cylindrical without any discontinuities and were therefore considerably stiffer than the noble alloy matrices. No fatigue studies involving both titanium matrix and ball patrix could be found in the dental literature.

O-ring matrices showed a progressive decrease in retention up to 1600 cycles, and after retention remained stable. Because of the high compliance of the O-ring, due to its low modulus of elasticity and its purely elastic behavior, the decrease in retention can only be related to progressive wear in the matrix. Neither plastic adaptation nor initial geometrical variations were observed as they were in the other groups, but wear was evident from the initial cycles. Already after 500 cycles, retentive values measured were below the theoretical limit of 0.5 kg necessary to guarantee an acceptable retention of the prosthesis.[16] These findings are in agreement with Fromentin et al,[6] but differ with Botega et al[5] who found substantially stable retention values for the two types of O-rings tested.

When comparing the behavior of the four groups, it can be noted that a stabilization of retention value was seen only in titanium and O-ring groups, where the wear phenomenon was exhausted and interferences of components reached a critical level. In the Teflon group, such critical levels were not observed at 5500 cycles, possibly because of the low friction coefficient of the material itself, and therefore, the low wear effect. In the noble alloy group, retention values were high over a simulated period of 3 years of function, and no wear was detected on the ball patrices.

The different behaviors observed in the four groups can be explained by the varying geometries, the different material properties, and the different coupling modalities. Plastic adaptation of the surfaces and wear can be identified as the two main causes of retention loss. The two phenomena will affect retention to a different extent depending on to the geometry of the attachment complex and the characteristics of the materials.

In the present study and from a clinical perspective, noble alloy and Teflon matrix groups exhibited the most desirable behavior. On the other hand, the high rate of wear observed in the titanium group seems to indicate the need for replacement of both the matrix and the ball patrix after a simulated function of 2 years.

It has been suggested that vertical movements, such as insertion and removal, are not the main cause for loss of retention of attachment systems over time. As for horizontal stresses occurring during masticatory function and parafunctional habits, fatigue studies are not able to replicate them.

Another limitation of most fatigue studies is the dry testing environment. In theory, wet fatigue studies are more representative of oral conditions, and the presence of a liquid can affect attrition coefficient, and consequently, wear of components. Other factors suggested to justify wear in vivo are quality and quantity of saliva, oral and prosthetic hygiene, and thermal changes.[5,6] A final limitation of this particular study is the fact that only five specimens were tested per each group. Testing with more specimens would allow for more powerful results to be obtained. Future research should develop in vitro settings that can better replicate stresses occurring on attachments under function in an environment that simulates the oral cavity.

Conclusions

Within the limitations of the present study the following conclusions can be drawn:

1. Different matrices for the same type of patrix provide different retention values.
2. Noble alloy and Teflon matrices showed the highest retention values without retention loss after a simulation of 3 years of insertions and removals.
3. Titanium matrix presented a continuous loss of retention, with the highest wear rate on ball patrix.

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