Effect of abutment angulation in the retention and durability of three overdenture attachment systems: An in vitro study

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PURPOSE. This in vitro study investigated and compared the durability and retention of three types of attachments. MATERIALS AND METHODS. Three commercially available attachments were investigated: Clix®, Dalbo-Plus® and Locator®. In total, 72 samples of these attachments were placed in the acrylic resin forms and subjected to mechanical testing (5400 cycles of insertion and removal) over the respective ball or Locator abutments immersed in artificial saliva at pH 7 and 37°C. The abutments were placed at angulations of 0°, 10° and 20°. The retention force was recorded at the beginning and after 540, 1080, 2160, 3240, 4320 and 5400 insertion-removal cycles. RESULTS. The results revealed that there were significant differences in the average values of the insertion/removal force due to angulation (F (2.48) = 343619, P < .05) and the type of attachment (F (7.48) = 23.220, P < .05). CONCLUSION. Greater angulation of the abutments was found to influence the retention capacity of the attachments, and the fatigue test simulating 5 years of denture insertion and removal did not produce wear in the metal abutments. [J Adv Prosthodont 2016;8:21-9]

KEY WORDS: Dental implants; Edentulous patients; Overdentures; Attachments

INTRODUCTION

Many types of attachment systems are currently available to retain overdentures. The purpose of these systems is to improve denture retention. However, in clinical settings, some problems have been found in certain types of attachment used, such as early loss of retention that leads to increase in the cost of treatment. A consensus statement from McGill University and the British Society for the Study of Prosthetic Dentistry determined that a two-implant overdenture should be the first choice of treatment for an edentulous mandible, and implant overdentures have become more popular.1,2 Moreover, with the insertion of implants, bone resorption has dramatically decreases when compared with conventional denture use.3,4 The attachment systems used in implant-supported overdentures have different retentive capacities and have either a bar attachment (splinted attachment system) or a conjunct of different unsplinted systems, such as spherical/ball types, magnets, telescopic crowns or stud-type attachments.5 The success of an implant-retained overdenture primarily depends on the retentive capacity of its attachment element to sustain its long-term functionality.6 A combination of metal-metal or metal-plastic/nylon contacts is normally used in an attachment system.7 The aim of this in vitro study was to evaluate the durability of variations in the retention force of three implant overdenture stud-type attachment systems at three different angulations in an aqueous environment of artifi-
cial saliva. The retention force was measured at the beginning and after 540, 1080, 2160, 3240, 4320 and 5400 insertion-removal cycles.

**MATERIALS AND METHODS**

Three commercial attachment systems were selected for the study: Clix®, Dalbo-Plus® and Locator®. The experimental groups were divided into red and yellow Clix attachments; Dalbo-Plus; and white, pink, blue, green, and red Locator attachments. Nine new samples for each group, provided in their original containers, were evaluated with 3 samples for each angulation, resulting in a total of 72 samples.

The artificial saliva used in this study was produced in the laboratory according to a previous study. The female component of each sample, in its original container, was incorporated into a small acrylic cylinder to simulate its location at the base of prosthesis. This was achieved by placing a mixture of thermopolymerizable acrylic (megaCRYL® N, Megadental, Germany) into acrylizing forms specifically designed to be incorporated into the test machine, CS-Dental Testing Machine and Pan Placement, for 10 to 15 min at 2 bars of pressure. A ratchet with the torque device and the corresponding adaptors of the abutments were used to incorporate corresponding implant analogues with a final torque of 20 N. The samples were placed into metallic forms specifically designed for the machine with angulations of 0°, 10° and 20° (Fig. 1).

The abutment and the attachments were placed inside the two pieces designed specifically for this machine (Fig. 2). The CS-Dental Testing Machine® has been described by Sergio Silva (2015). The testing machine was programmed with a working crosshead speed of 1.06 mm per second, which was produced by an electric motor with 0.2 KW. A load cell with a measuring range of ± 30000 g, was used to register the forces. After following the driving and calibration protocols to test the machine, 5400 insertion-removal cycles were performed to simulate 5 years of wear, and the wear (removal/insertion values) was registered at 8 different time points (initial, 1 month, 6 months, 1 year, 2 years, 3 years, 4 years, and 5 years). All samples were immersed in artificial saliva at pH 7 and 37°C during the test to simulate oral conditions. The temperature was programmed at 37°C and controlled automatically by a thermal resistance of 100 W and a sounding of PT100. Data were collected using a pen drive in a USB port in the machine. Each file registered approximately 250,000 read points transmitted by the load cell. An Excel spreadsheet was used to select the desired cycles for this study. The surface characteristics were also evaluated using a microscope stereoscope (Olympus SZ61, Tokyo, Japan) with a 90× magnifier and a digital camera incorporated into the microscope.

![Fig. 1. Female (A) and male (B) supports at angulations of 0° (B), 10° (C) and 20° (D).](image)

![Fig. 2. Samples inside the CS Dental Machine. Male (A) immersed in artificial saliva and Female (B) inside the metallic form.](image)
All statistical analyses were performed using IBM® SPSS® Statistics software version 22.0 (SPSS Inc., Chicago, IL, USA), and $P < .05$ was considered statistically significant.

In order to assess the influence of the angulation and attachment factors on the average value of the insertion force at the eight evaluated times, ANOVA with repeated measures was performed.

Taking into account the experimental design, for an alpha value of 0.05, a power of 0.95, and a square eta of 0.5 ($f = 1.0$, effect size) and using a threshold value for correcting the nonsphericity used, the program G * Power 3.1.9.2® indicates the minimum required value for the global sample to be 54.

If we consider $n = 72$, the calculation made using G * Power 3.1.9.2® reduces the effect size to 0.616, keeping the other parameters unchanged.

The assumption of normality was assessed using the Shapiro-Wilk test with $P > .05$ for all evaluated time points according to the angulations and the type of attachments.

The assumption of sphericity was tested with Mauchly’s test ($P < .05$), which rejected the sphericity of the data. Because the estimated value of epsilon was less than 0.75, a Greenhouse-Geisser correction was used for the interpretation of the results for intra-subject effects.

**RESULTS**

The retention forces of the three types of attachments were evaluated by analyzing the values of the insertion and removal independently. The values were expressed in gf.

An analysis of the results revealed that there were significant differences in the average value of the insertion force at different time points; that is, there was a significant variation in the average value of the insertion force over time, and this value increased significantly over time (Fig. 3).

There were no significant differences in the average value of the insertion force due to the interaction of time and angulation ($F (3.866; 92.791) = 0.870, P > .05$), indicating that the group averages (angulations of 0°, 10° and 20°) were identical to the eight evaluated times. These findings are reflected by the parallel lines in Fig. 4.

There were significant differences in the average value of the insertion force due to the interaction of time and attachment ($F (13.532; 92.791) = 8.161, P < .05$), indicating that the group averages (Clix, Locator and Dalbo-Plus) were different at the eight evaluated times; that is, the average value of the insertion force was not the same for the three different attachments. These findings are reflected by the lack of parallel lines in Fig. 5.

There were no significant differences in the average value of the insertion force due to the interaction of time with angulation and attachment ($F (27.064; 92.791) = 1.279, P > .05$), indicating that the average group values were identical at the eight evaluated times (Fig. 6).

An analysis of the results revealed that there were significant differences in the average value of the removal force at the different time points; that is, there was a significant variation in the average value of the removal force over time, and this value decreased significantly over time (Fig. 7).

There were no significant differences in the average value of the removal force due to the interaction of time and angulation ($F (5.978; 143.467) = 1.499, P > .05$), indicating that the group averages (angulations of 0°, 10° and 20°) were identical at the eight evaluated times. These findings are reflected by the parallel lines in Fig. 8.

There were significant differences in the average value of the removal force due to the interaction of time and attachment ($F (20.922; 143.467) = 8.053, P < .05$), indicating that the group averages (Clix, Locator and Dalbo-Plus)
were different at the eight evaluated times; that is, the average value of the removal force was not the same for the three different attachments. These findings are reflected by the lack of parallel lines in Fig. 9.

There were significant differences in the average value of the removal force due to the interaction of time with angulation and attachment (F (41.845; 143.467) = 2.010, P < .05), indicating that the average group values were not identical at the eight evaluated times (Fig. 10).

The percentage of retention loss in the removal force was evaluated and compared to the baseline measurement. Negative values indicated gains in removal force because this force was evaluated in negative numbers, meaning that the recorded data in the machine test presented positive numbers for the insertion force and negative numbers for the removal force (Table 1).
Fig. 9. Removal force averages for the different attachments.

Fig. 10. Removal force averages for the different attachments at angulations of 0°, 10°, and 20°.

Table 1. Percentage of loss of retention in removal force compared to baseline

| Angulation | 0°     | 6 months | 1 year | 2 years | 3 years | 4 years | 5 years | 10°     | 6 months | 1 year | 2 years | 3 years | 4 years | 5 years | 20°     | 6 months | 1 year | 2 years | 3 years | 4 years | 5 years |
|------------|--------|----------|--------|---------|---------|---------|---------|--------|----------|--------|---------|---------|---------|---------|--------|----------|--------|---------|---------|---------|---------|--------|
|            |        |          |        |         |         |         |         |        |          |        |         |         |         |         |        |          |        |         |         |         |         |        |
| Attachments| Yellow Clix | Red Clix | Dalbo-Plus | Pink Locator | White Locator | Blue Locator | Red Locator | Green Locator |
| 0°         | 14.8%  | 9.4%     | -18.4% | 2.9%    | -30.4%  | 7.0%    | 7.8%    | 0.6%  |
|            | 16.2%  | 12.0%    | -65.9% | 6.1%    | -5.4%   | -9.4%   | -34.9%  | 17.0% |
| 1 year     | 9.2%   | 13.3%    | -58.1% | 7.3%    | 0.4%    | -2.4%   | -47.4%  | 19.4% |
| 2 years    | 15.4%  | 19.9%    | -64.5% | 12.6%   | 1.8%    | -13.4%  | -56.0%  | 23.5% |
| 3 years    | 19.2%  | 22.7%    | -48.4% | 7.6%    | 12.0%   | -14.2%  | -61.3%  | 24.4% |
| 4 years    | 24.9%  | 24.4%    | -47.1% | 6.3%    | 14.4%   | -13.5%  | -56.3%  | 23.9% |
| 5 years    | 30.4%  | 25.7%    | -39.6% | 6.4%    | 17.9%   | -12.0%  | -51.3%  | 28.1% |
| 10°        | -5.3%  | 9.2%     | -15.6% | 31.9%   | 20.5%   | -4.7%   | -2.2%   | -1.2% |
| 6 months   | -0.6%  | 12.8%    | -31.7% | 27.6%   | 44.6%   | -15.1%  | -30.0%  | -23.6% |
| 1 year     | -5.4%  | 12.1%    | -47.6% | 32.6%   | 48.1%   | -7.1%   | -40.9%  | -22.2% |
| 2 years    | -2.4%  | 18.2%    | -44.2% | 29.4%   | 53.3%   | -1.5%   | -51.2%  | -22.2% |
| 3 years    | 4.8%   | 20.5%    | -41.4% | 31.5%   | 55.0%   | -20.8%  | -49.5%  | -15.8% |
| 4 years    | 9.8%   | 17.9%    | 4.0%   | 27.6%   | 58.9%   | -40.8%  | -40.2%  | -18.1% |
| 5 years    | 15.0%  | 20.9%    | 0.4%   | 29.5%   | 58.6%   | -6.0%   | -38.7%  | -11.6% |
| 20°        | 14.1%  | 16.3%    | -17.5% | 21.4%   | 6.0%    | -11.4%  | 8.0%    | -3.2% |
| 6 months   | 15.8%  | 25.2%    | -48.2% | 22.9%   | 12.9%   | 3.8%    | -20.0%  | -56.8% |
| 1 year     | 15.7%  | 23.5%    | -36.2% | 9.5%    | 22.2%   | -1.9%   | -29.8%  | -102.2%|
| 2 years    | 15.2%  | 27.9%    | -52.9% | 12.5%   | 27.0%   | 15.9%   | -68.5%  | -104.6%|
| 3 years    | 12.8%  | 32.8%    | -31.4% | -75.7%  | 34.0%   | 12.4%   | -62.0%  | -135.0%|
| 4 years    | 13.8%  | 34.8%    | -13.8% | -53.9%  | 30.4%   | 18.0%   | -42.0%  | -84.6% |
| 5 years    | 17.5%  | 35.5%    | -28.8% | -39.3%  | 24.8%   | 12.7%   | -41.3%  | -63.8% |
Before and after being subjected to 5400 cycles of insertion and removal, all the attachments and abutments were observed with a stereoscope (Olympus SZ61) and 90× magnifier to evaluate any changes in their surfaces. The diameters of the abutments were also measured with a digital micrometer to evaluate any changes.

Regarding the metal abutments, there were no differences in the values of their diameters before and after the 5400 cycles of insertion and removal. The ball abutments had an average value of approximately 2.25 mm, and the locator abutments had an average value of 3.86 mm.

No visible wear was detected in the surfaces of the abutments. However, in the female components, some apparent deformation was detected, particularly in the internal part of the white, pink and blue Locators (Fig. 11).

DISCUSSION

In this in vitro study, 5400 cycles were used to simulate an in vivo function of 5 years based on an average of 3 removal-insertions of the overdentures per day for oral hygiene procedures. The use of artificial saliva is the standard in in vitro studies to simulate wear and to promote lubrication of the attachment components. These types of tests are commonly used to obtain important information. Attachment retention forces of 5 to 20 N are sufficient to provide retention in overdentures. The three commercial attachments investigated allow an easy exchange of the female parts when the tool indicated by the manufacturer is used. This parameter is in agreement with the studies of Cohen et al. and Trakas et al.

In both the yellow and red Clix samples at an angulation of 0°, the retention force decreased over time from an initial value of 862 g and 8.45 N by 30.40% (1238 g - 12.14 N) in the yellow Clix and by 25.70% (754 g - 7.4 N) in the red Clix. In the red Clix sample, it was verified that a larger angulation required more strength of removal force at an angulation of 20°, and the initial retention force was greater (1373 g - 13.47 N), but over time, the loss of retention force was also higher, with values of 35.5% (886 g - 8.68 N) at an angulation of 20° compared to a loss of 20.90% (1037 g - 10.16 N) at an angulation of 10°.

Ortega et al. used Preci-Clix attachments over implants with different angles between the matrix and matrix according to the axis of insertion at an angulation of 0°. Test groups combined a matrix and matrix of 0°, 10° and 15° and after 3,500 fatigue cycles and found that these inclinations had influence over time in the retention force and that at an angulation of 10°, the retention force was lower than at an angulation of 15°. Our results showed that in the Clix group, the angulation of the abutments influenced the retention force, which means that more angulation required more retention force, but over time, the loss is greater. However, the final value of the retention force is acceptable to retain an overdenture.

All the samples of Dalbo-Plus system presented initial retention forces adequate to retain an overdenture. The initial mean values for removal force varied from 1003.70 g (9.83 N) to 1602.30 g (15.71 N) depending on the angulation. The Dalbo-Plus system presented a greater insertion force over time. There were significant differences in the mean values of removal force due to the interaction of time with angulation and type of attachment (F (41.845; 143.467) = 2.010, value P < .05), indicating that the group averages were different at the eight evaluated times. According to the results of the test on the effects of the fac-

Fig. 11. White Locator samples (A in initial and B, C at the end) and abutment (D, E in initial and F, G at the end) before and after the 20° test.
tors, it was verified that there are significant differences in the mean value of the removal force due to angulation (F (2,48) = 34.619, value P < .05), type of attachment (F (7,48) = 23.220, P-value < .05), and interaction (F (14) (0.48) = 5.209, value P < .05).

The Dalbo-Plus system presented gains in insertion and removal forces throughout the study, unlike the results from other published studies on angulation. Gains of 39.60% removal forces throughout the study, unlike the results cycles, but at 2000 cycles, they obtained a value of 5 N. in the mean value of the retention force in the first 500 study by Rutkunas et al.,22 who found initial average values provided by the resilience of Teflon, or external retention over the abutment. Retention values higher than those indicated by the manufacturer were found in the green Locator samples (1311.3 g). This may explain the discrepancies found in our results.

The red Locator samples had gains in the removal force at all angulations. Those gains were evident up to 3240 cycles and then progressively declined until 5400 cycles. At an angulation of 0°, a mean value of removal force of 996.70 g (9.77 N) was obtained. At an angulation of 10°, gains were on the order of 38.70% with a mean value of 1001.67 g (9.82 N), and at 20° the lowest values of removal force for this group were obtained, with a gain of 41.30% corresponding to 200.67 g (1.96 N), which is insufficient to retain an overdenture. We think that the origin of
these values was the composition of the Teflon, which would have little resistance because despite obtaining insertion force values of 742.33 g (7.27 N) at the beginning and 1543.66 g (15.13 N) at the end of the study, the removal force at an angulation of 20° was very low. The green Locator behaved in a similar manner to the red Locator, losing removal force over time at an angulation of 0°, but gaining force at angulations of 10° and 20°, although at values too low to retain an overdenture. The mean value in the removal force at an angulation of 20° was 273.03 g (2.67 N) at the end of the study, which was clearly lower than that referenced by different authors to retain an overdenture.10,14-16,27-31

In an in vitro study conducted by Uludag et al.32 of 3 implants at the middle level in canines with an angulation of 20°, the green Locator showed a loss of 20% in removal force at the end of 540 cycles but maintained average values that were adequate to retain an overdenture (47 N). Friction, water absorption and/or thermal expansion of Teflon can contribute to dimensional changes in plastic parts of attachments.25 By contrast, in the mouth, functional and parafunctional movements may cause deformation in the plastic parts, resulting in a decrease of removal force or even a rupture of the attachment. Discrepancies between clinical findings and in vitro fatigue tests indicate that wear cannot be adequately simulated by using the current in vitro approaches. The three dimensional movement of an overdenture during function, angulation of implants, effects of cleaning agents, food, aging of the plastic parts, and fatigue of the metal parts are indicated as possible causes of these disagreements. Currently, given the complexity of simulated clinical conditions, the results of in vitro studies should only serve as an empirical orientation.

The macroscopic analysis of the abutments was performed before and after testing with the use of a digital micrometer. No relevant macroscopic differences were found in the metal parts. The ball abutments had a mean diameter of 2.25 mm, and the Locator abutments had a mean diameter of 3.86 mm; there were no changes to either group as a result of the tests. Therefore, we can say that no wear of the metal abutments occurred. Metal waste in the abutments was not found, which would have confirmed some type of wear. All 72 attachments, 18 ball abutments, and 15 Locator abutments, which had previously been separated in individual boxes, were observed at the beginning and at the end of the test using a stereoscope (Olympus® SZ61) with enlargements of 90x and a camera (Olympus® SC30) built in for the registration and evaluation of wear produced during fatigue tests. A comparison of the initial and the final photos of each sample showed a small amount of wear (Fig. 11). In relation to angulation, a macroscopic deformation of specimens with areas of material loss was larger in samples at 20° than at 0°. The white Locator showed signs of wear on the inside as well as deformation of internal parts. Factors such as hardness, resilience or elasticity mode intrinsic to each material were fundamental to the wear observed in various combinations of attachments used throughout the study. Türk et al.33 evaluated samples by microscopy (SEM) after 5000 fatigue tests and found that the metal abutments did not show significant differences in their diameters, and no signs of wear were observed. The authors concluded that wear in metal parts could not be verified after 5000 cycles.33 Kobayashi et al.5 also concluded that the Dalbo-Plus and Locator systems showed no wear after 14600 cycles of insertion and removal.

CONCLUSION

Within the limitations of this study, the following conclusions were drawn: greater angulation of the abutment values was found to influence the retention capacity of the attachments, the attachment systems evaluated in this study presented adequate retention for clinical usage, the fatigue test simulating 5 years of denture insertion and removal did not produce wear in metal abutments. Overall, the Dalbo-Plus system provided the best retention followed by the white Locator system.

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