Attachment Systems for Mandibular Single-Implant Overdentures: An In Vitro Retention Force Investigation on Different Designs

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Purpose: The aim of this study was to investigate the retentive force of six different attachment systems used for mandibular single-implant overdentures, including two prototype large ball attachment designs. ***Materials and Methods:*** Two prototype ball attachments of larger dimensions (7.9 and 5.9 mm) and four commercially available ball and stud attachments of standard dimensions (2.25 and 4.0 mm) were evaluated on three identical test casts resembling an edentulous mandible with severe residual ridge resorption. Five samples from each attachment system (n = 30) were connected to three different implants (8.0-mm wide diameter, 3.75-mm regular diameter, and 4.0-mm regular diameter). An Instron testing machine with a computer software package was used to deliver a vertical dislodging force at a cross-head speed of 50 mm/min to each overdenture sample from the anterior direction. A total of 300 pull tests were conducted (50 per attachment system). The maximum load (retentive force) required to separate each overdenture from the supporting implant was then measured. ***Results:*** The highest retentive force (36.97 ± 2.23 N) was achieved with the 7.9-mm prototype ball attachment design, followed in a decreasing order by the 5.9-mm prototype ball attachment design (32.06 ± 2.59 N), the standard 2.25-mm ball attachment (17.32 ± 3.68 N), Locator white (12.39 ± 0.55 N), Locator pink (9.40 N ± 0.74 N), and Locator blue (3.83 ± 0.64 N). A statistically significant difference ($P < .0001$) was found between all attachments. ***Conclusions:*** Attachment systems of larger dimensions provided higher retentive forces for mandibular single-implant overdentures. Further in vitro and in vivo research is necessary to determine prosthodontic outcomes with these attachments in edentulous patients prior to their routine clinical use internationally. *Int J Prosthodont 2010;23:160–166.*

Recent epidemiologic and demographic reports have projected an increase in the number of aging edentulous patients in most countries.[1,2] Treatment paradigms for edentulous mandibles with implant-supported prostheses have traditionally offered the option of placing fewer implants when supporting a mandibular overdenture.[3,4] Long-term treatment outcomes indicate that two implants are currently considered adequate to support an overdenture when opposing a complete maxillary denture.[5–7] However, despite its proposal as a minimal intervention, mandibular two-implant overdenture treatment still remains inaccessible to many edentulous elderly patients in different countries and socioeconomic groups.[8] An alternative approach is a mandibular overdenture supported by a single midline implant to oppose a complete maxillary denture.[9] Information from case reports and prospective studies have demonstrated the possibility of a successful outcome with this approach as well.[10–12]

The prosthodontic literature has always acknowledged that retention and stability are the major determinants of success for complete dentures[13–15] and mandibular two-implant overdentures.[16,17]

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Mandibular single-implant overdentures opposing complete maxillary dentures could become more successful with optimum retention and stability. Retention and stability are the function of the specific attachment system selected to connect the implant to the overdenture.[18] A retentive force high enough to prevent overdenture displacement has been identified as an essential requirement for a successful attachment system.[19] Currently, a universally accepted threshold value of retentive force for attachment systems remains elusive in the literature. However, some investigators have proposed a rough estimate of 20 N of retentive force to be adequate for mandibular two-implant overdentures.[19] The retentive force is gained from mechanical and frictional contacts, or from magnetic forces of attraction between the patrices and matrices of various attachment systems.[20,21]

The determination of retentive force for attachment systems used with mandibular overdentures on two or more implants has been extensively investigated under in vitro[19,22–30] and in vivo conditions.[31–33] A wide range of retentive forces from as low as 1 N to as high as 85 N have been reported for a multitude of bar, ball, stud, and magnetic attachment systems. Conversely, specific in vitro investigations of attachment systems for mandibular single-implant overdentures that simulate a clinical situation are limited.[34] That study was limited in that it only compared the stability of the overdentures on one or two implants. Therefore, actual retentive force investigations of attachment systems for mandibular single-implant overdentures are currently lacking.

The purpose of this study was to investigate the in vitro retentive force of six different attachment systems for mandibular single-implant overdentures, including two prototype large ball attachment designs.

Materials and Methods

The methodology used in the present investigation was adapted from a method previously used with mandibular two-implant overdentures.[26]

Test Casts and Implant Systems

Three identical test casts resembling an edentulous mandible devoid of any tissue undercuts were fabricated from a single silicone mold using a pour-type acrylic resin cast material (Exakto-Form, Bredent). The casts depicted severe residual ridge resorption (category D/E), as indexed by Lekholm and Zarb.[35] Using a precision milling machine (Metalor Technologies), the midline area of each mandibular cast was prepared to receive one of three implants: wide 8.0-mm diameter (Southern Implants), regular 3.75-mm diameter (Southern Implants), or regular 4.0-mm diameter (Neoss International). Each implant was coated with a thin layer of an acrylic resin adhesive (MDS Products) prior to placement.

Attachment Systems

Two new prototype ball attachments of larger dimensions and four commercially available attachment systems of standard dimensions were evaluated.

- One prototype ball attachment (design 1) composed of 7.9-mm-diameter titanium, titanium nitride-coated ball patrix, and an 8.6-mm-diameter plastic matrix (Southern Implants).
- Another prototype ball attachment (design 2) composed of 5.9-mm-diameter titanium, titanium nitride-coated ball patrix, and a 7.6-mm-diameter plastic matrix (Southern Implants).
- A standard 2.25-mm ball attachment composed of 2.25-mm-diameter titanium alloy ball patrix (Southern Implants) and a 3.0-mm-diameter Dalla Bona type gold alloy matrix (Alphadent).
- Three Locator attachments (white, pink, and blue versions) all composed of 4.7-mm-diameter nylon male inserts and 4.0-mm-diameter titanium alloy, titanium nitride-coated female abutments (Zest Anchors).

The exact material specifications are outlined in Table 1. Five samples from each of the 6 attachment systems were randomly selected, with each sample comprising one abutment (patrix) and a matching matrix (Fig 1). Therefore, a total of 30 attachment samples were used for this research.

Overdenture Samples

A complete mandibular denture wax-up with artificial acrylic resin teeth (Vivodent, Ivoclar Vivadent) was constructed. This was then duplicated in cold-curing clear acrylic resin material (Castapress, Vertex). Twenty identical clear acrylic resin overdenture samples were produced. The matrices were incorporated into the intaglio surface of the overdentures using a direct pick-up technique. Since the Locator attachment system, by virtue of its design, allows for the interchanging of its nylon male inserts, only 5 overdenture samples were used for all 15 Locator attachments (white n = 5, pink n = 5, and blue n = 5). Each overdenture sample was fit with two stainless steel hooks, one in each side of the buccal flange.

Table 1 Specifications of Attachment Systems

Attachment system	Description	Material	Dimension*
Patrix			
Ball attachment prototype design 1†	One-piece large flat-top titanium ball with a retaining screw; platform-matched to the implant	Unalloyed grade 4, titanium, titanium nitride-coated	7.90-mm diameter, 6.5-mm base diameter, 2.00-mm transmucosal height, 6.4-mm total height
Ball attachment prototype design 2†	One piece large titanium ball with a retaining screw; platform-switched to the implant	Unalloyed grade 4 titanium, titanium nitride-coated	5.90-mm ball diameter, 5.00-mm base diameter, 2.00-mm transmucosal height, 6.7-mm total height
Standard 2.25-mm ball attachment‡	Two piece ball abutment made of a transmucosal cylinder and a ball-top screw	Grade 5 titanium alloy	2.25-mm ball diameter, 2.0-mm transmucosal cylinder height
Locator attachments (white, pink, and blue)§	Nylon male insert contained within a titanium alloy denture housing cap	Nylon DuPont Zytel 101L NC-10	4.7-mm outer diameter, 1.7-mm height
Matrix			
Ball attachment prototype design 1†	Pink plastic matrix with retentive grooves	Hostaform (polyoxymethylene copolymer)	8.6-mm outer diameter, 4.0-mm height
Ball attachment prototype design 2†	Pink plastic matrix with retentive grooves	Hostaform (polyoxymethylene copolymer)	7.6-mm outer diameter, 5.0-mm height
Standard 2.25-mm ball attachment‡	Dalla Bona type gold alloy matrix with retentive lamellae	Orax alloy (Au, Pt, Ag, Cu)	3.0-mm diameter, 2.8-mm height
Locator attachments (white, pink, and blue)§	One-piece titanium female abutment	Grade 5 titanium alloy, titanium nitride-coated	4.00-mm diameter, 2.0-mm transmucosal height

*Dimensions were obtained from the respective manufacturers. When not available, direct measurements were made (Dentagauge 3, ErskineDental).
†Used with wide 8-mm-diameter, 6.5-mm-platform Max-8 implant (Southern Implants).
‡Used with regular 3.75-mm-diameter implant (Southern Implants).
§Used with regular 4.0-mm-diameter implant (Neoss International).

Fig 1a *(left)* Prototype ball attachment (design 1): 8.6-mm-diameter pink plastic matrix composed of Hostaform (polyoxymethylene copolymer) *(top)*, 7.9-mm-diameter ball patrix composed of titanium with titanium nitride coating *(bottom left)*, and the abutment screw *(bottom right)*.

Fig 1b *(right)* Prototype ball attachment (design 2): 7.6-mm-diameter pink plastic matrix composed of Hostaform (polyoxymethylene copolymer) *(top)*, 5.9-mm-diameter ball patrix composed of titanium with titanium nitride coating *(bottom left)*, and the abutment screw *(bottom right)*.

Fig 1c *(left)* Standard 2.25-mm ball attachment: 3.0-mm-diameter Dalla Bona type gold alloy matrix *(left)*, 2.25-mm-diameter ball patrix composed of titanium alloy *(bottom right)*, and the transmucosal cylinder *(top right)*.

Fig 1d *(right)* Locator attachment: White *(bottom left)*, pink *(center left)*, and blue *(top left)*, all 4.7-mm outer diameter, composed of Nylon DuPont Zytel 101 L NC-10 (metal housing of inserts not seen in image) and the female abutment, 4.0-mm diameter, composed of titanium alloy with titanium nitride coating *(right)*.

Testing Apparatus

A dual-column universal material testing machine (Instron 3369, Instron) was used to induce the tensile force tests. The machine was equipped with a computer interface software package (BlueHill 2) containing a tensile application module setup. This application module is provided with an automatic slack correction feature, allowing the cross-head of the machine to move and self-adjust to compensate for any slack that may be present. A 5-kN load cell was selected and affixed to the horizontal load frame of the Instron machine and the cross-head speed was set at 50 mm/min. This speed approximates the actual speed of movement of an overdenture away from its retentive elements in the mouth under a vertical dislodging force.[26,36]

Tensile Test Setup

Each test cast containing the implant and the corresponding overdenture sample of each system to be investigated was fixed to a metallic base on the machine platform. A double strand of a nonresilient, soft-braided nylon cord 38 cm in length and 1.5 mm in diameter was connected at each end to the two metal hooks passing over the cross bar of the load cell. Two small metal rings were used to stabilize the nylon cord at each side of the overdenture. A preload value of 1 N was set, at which the gauge length of the load cell reset automatically just prior to the initiation of the actual pull. This feature ensured that the resulting strain values were recorded accurately at the new gauge length. The tensile test set-up was designed to induce a vertical dislodging force to the overdenture from the anterior direction, simulating actual clinical situations. The maximum load needed to dislodge the overdenture from its supporting implant (retentive force) was recorded automatically and plotted. Each attachment sample was subjected to 10 vertical pull tests. A 10-second interval was allowed between tests for the elastic recovery of the attachment components.[27] A total of 300 pull tests were conducted for all 30 attachment samples.

In addition, to gain insight into the mode of retention of these attachments, one fresh patrix-matrix assembly from each attachment system was oriented vertically and embedded in a block of clear acrylic resin of approximately 2 × 2 × 1.5 cm. The attachment assembly within the acrylic block was then sectioned longitudinally (Accutome 50, Struers). The sectioned side was viewed under ×10 magnification (Nikon Measurescope) to delineate the physical contact relation between the respective patrices and matrices of each attachment system under evaluation.

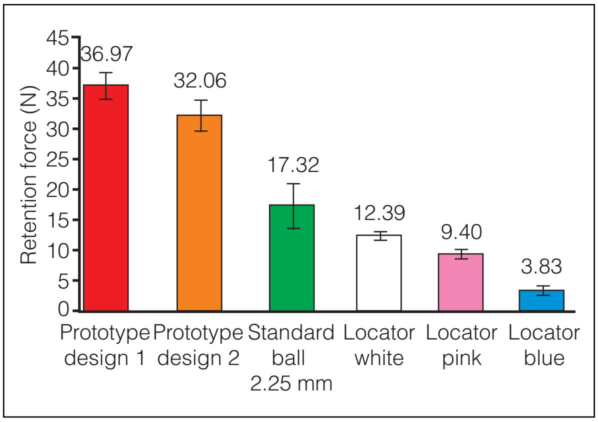

Fig 2 Mean retentive force and standard deviation of attachment systems. A significant difference was found between all attachment systems ($P < .0001$).

Statistical Analysis

The mean retentive force and standard deviation for each attachment system was calculated. A one-way analysis of variance test was performed using the Statistical Package for Social Sciences (version 15, SPSS) to determine if any significant difference exists between the six attachment systems. In addition, the Bonferroni and Tukey post hoc tests were used to identify specific differences. All statistical analyses were considered significant at the $P < .05$ level.

Results

The mean retentive force and standard deviation for the six attachment systems is illustrated in Fig 2. The retentive forces ranged between 36.97 N (± 2.23) and 3.83 N (± 0.64). The Bonferroni and Tukey post hoc tests showed that the mean values of each attachment type were significantly different from one another ($P < .0001$). The highest retentive force among all attachments was obtained with the prototype design 1 (36.97 N ± 2.23), while the lowest was that of the Locator blue attachment (3.83 N ± 0.64). Prototype design 2, followed by the Dalla Bona type gold alloy matrix, Locator white, and Locator pink attachments complete the statistical analysis in a decreasing order of retentive force.

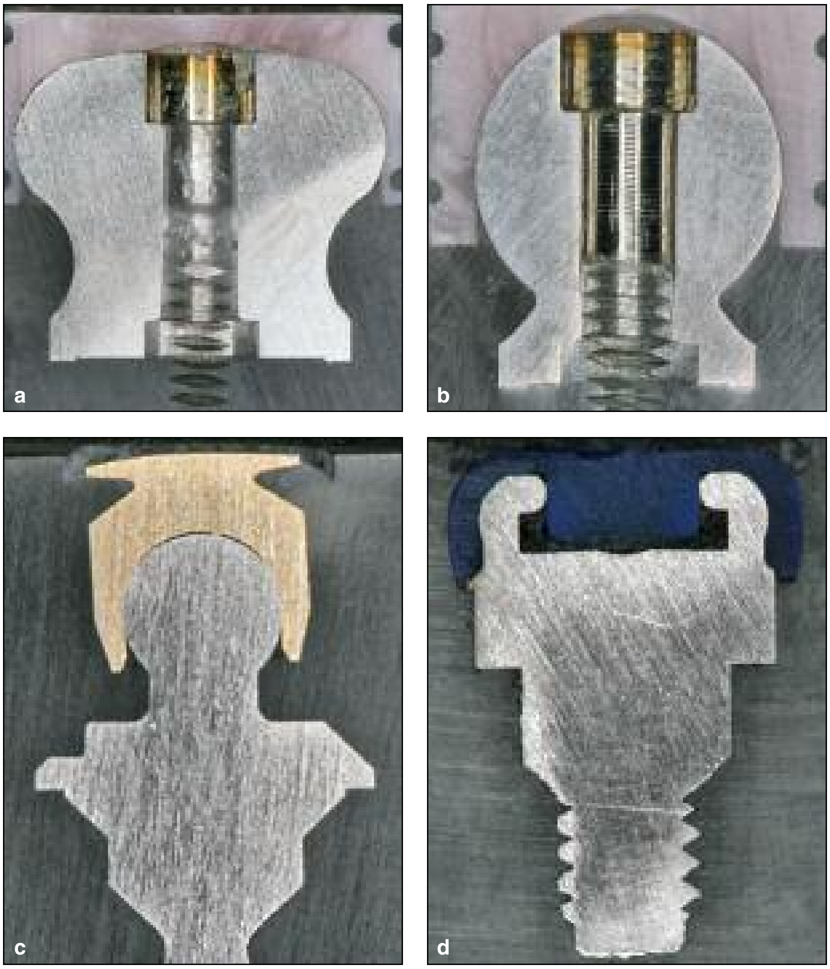

Fig 3 Cross sections of the attachment systems. **(a)** Matrix-patrix assembly of prototype design 1; **(b)** matrix-patrix assembly of prototype design 2; **(c)** matrix-patrix assembly of the standard 2.25-mm-diameter ball attachment; **(d)** nylon male insert-female abutment assembly of the Locator blue attachment.

Observation of the cross-sectioned attachment systems under the microscope revealed that only frictional retention could be expected from these attachments (Figs 3a to 3d). The large plastic matrices of prototype ball attachment designs 1 and 2 enclose their respective ball-shaped patrices and pass over the height of contour of these patrices without engaging the undercut areas below (Figs 3a and 3b). The Dalla Bona type gold alloy matrix of the standard 2.25-mm-diameter ball also reflected a similar pattern, but the lamellae of the gold matrix were observed to just encroach the undercut below the contour height of the ball patrix (Fig 3c). On the other hand, the central stud of the nylon male insert of the Locator blue attachment (representing all three Locator attachment systems since they are all of the same design) press fits within the inner metal ring of the female abutment while its outer margin simultaneously and completely engages the shallow undercut area present at the outer margin of the abutment (Fig 3d).

Discussion

This in vitro study investigated the retentive force of six different attachment systems (including two prototype designs) for mandibular single-implant overdentures. The test methodology employed was designed to emulate an actual clinical scenario. The obvious limitation in this study is that the retentive force was evaluated only during simulated overdenture removal. Under in vivo function in patients, it is acknowledged that a mandibular overdenture on a single implant would tend to rotate in multiple directions. These multidirectional movements are difficult to simulate in vitro, hence, findings of previous research are also accepted with limited clinical relevance.[19,27]

The authors have shown that higher retentive forces can be achieved with prototype ball attachment designs of larger dimensions (7.9- and 5.9-mm-diameter ball patrices). The rationale for the design was based on the assumption that wider surface areas of frictional contact between the patrices and matrices of larger attachments would increase their physical retention. Considering that these two attachment systems are of identical material composition and mode of retention, the difference in the retentive force between the two designs can only be attributed to the dimensional differences. This agrees with previous findings on two similar ball attachment systems of 2.0- and 2.15-mm-diameter patrices where higher retentive force was observed with the larger attachment.[25] The standard 2.25-mm-diameter ball attachment with Dalla Bona type gold alloy matrix presented a mean retentive force of 17.32 N. The dimensions of this attachment are similar to many other ball attachments from different systems (ball attachment 2.25 mm, Nobel Biocare; retentive anchor, Straumann; ball attachment, Astra Tech; Dalla Bona, Lifecore Biomedical; Dal-Ro, Biomet 3i). These attachments have been investigated previously under in vitro conditions[19,22,23,29,37] and a retentive force range between 17.80 and 85 N was reported. Extrapolating findings from the present study on the retentive force of the standard 2.25-mm ball attachment to those described previously is affected by specific variations in material composition among these attachments.

The three Locator attachments investigated in this study revealed three significantly different levels of retentive forces. This matches the manufacturer's recommendation of selecting different levels of retention depending on patient need. It is relevant, however, that the retentive forces reported here fall short of the manufacturer's preset values for these attachments. This research also revealed that despite the widespread use of the Locator attachments internationally, there are only limited in vitro reports on the retentive force of these attachments.[27,28] A 10.60-N retentive force was reported for a single Locator pink attachment,[27] which approximates the current findings. On the other hand, retentive forces of 28.95 N and 12.33 N were reported but for paired Locator white and pink attachments, respectively.[28] Direct comparison with the values reported in this study could be flawed considering that only single attachments were used. The mode of retention observed with the Locator attachments is also frictional. This results from the dimensional misfit between the slightly oversized nylon male insert and the smaller diameter inner ring of the female abutment. Hence, the variable levels of retentive forces observed with the three Locator attachments could be attributed to minute incremental differences in the dimensions of the nylon male inserts of these attachments.

Given the retentive forces presented in this study, larger attachment systems could be a realistic option for mandibular single-implant overdentures clinically. This is obviously accepting that retention of the overdenture will only be gained from a single attachment. Moreover, improved patient acceptance of implant overdenture treatment has shown to correlate with the improved retentive quality of the overdenture.[16,17] The authors acknowledge, however, that larger attachments would require additional space within the intaglio surface of the overdenture, implying a greater propensity to overdenture fracture. This is clinically relevant considering that prosthesis fracture of both single- and two-implant mandibular overdentures has been reported as part of prosthodontic maintennace.[7,12,33,38] The elimination of nonfunctional parts of attachment systems to minimize their space requirements within the denture bases, therefore, has been recommended.[39] However, within the context of the current clinical scenario of severe residual ridge resorption (type D or E), the width between the mental tubercles and the genial tubercles is wide and favorable.[40] The application of larger attachments for these patients need not compromise other prosthodontic outcomes related to phonetics or esthetics since it is believed that the amount of acrylic resin in the area replaces only the residual ridge resorption, and hence, bulk around these attachments is not necessary.

As a result, any proposal for a paradigm shift from attachment systems of standard dimensions to attachment systems of larger dimensions specifically designed for use with mandibular single-implant overdentures still needs further validation. There is a need for additional in vitro research, as well as positive outcomes from randomized controlled clinical trials.

Conclusion

Within the limitations of this in vitro investigation, prototype attachment systems of larger dimensions provide higher retentive forces for mandibular single-implant overdentures.

Acknowledgments

The authors would like to thank Southern Implants and Neoss International for supporting this research in terms of implant components. They also would like to thank Neil Waddell, Senior Lecturer/Dental Technician, Oral Implantology Research Group, Sir John Walsh Research Institute, School of Dentistry, University of Otago, New Zealand, for his assistance with the equipment setup.

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