Attachment Systems for Mandibular Two-Implant Overdentures: A Review of In Vitro Investigations on Retention and Wear Features

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Purpose: The aim of this study was to review the published literature on in vitro articles investigating the retentive force or wear features of different attachment systems, specifically for mandibular two-implant overdentures using an unsplinted prosthodontic design. ***Materials and Methods:*** An electronic search was performed through PubMed, Embase, and Medline databases using Boolean operators to combine the following key words: "retention," "wear," "overdenture attachments," "attachment systems," "implant-retained overdentures," and "implant-supported overdentures." The search was limited to articles written in English published up to October 2008. In addition, a hand search through articles and reference lists retrieved from the electronic search and peer-reviewed journals was also conducted. ***Results:*** From a total of 193 articles, only 15 met the specified inclusion criteria for the review. These articles provided evidence that the majority of attachment systems for mandibular two-implant overdentures demonstrate a reduction in their retentive force under in vitro conditions. Wear was unquestionably implicated as the etiologic factor for the loss of retention; however, the specific mechanisms involved in the wear process have not been researched adequately. Findings from the literature have also implicated several factors that influence the retentive force of the attachment system and its wear features; compelling evidence on its precise role however, is still lacking. ***Conclusions:*** Further in vitro investigations of the factors involved in the retention and wear of attachment systems for mandibular two-implant overdentures are still needed. These factors must be investigated separately under well-controlled conditions to limit the influence of confounding variables on their outcome. *Int J Prosthodont 2009;22:429–440.*

According to the *Glossary of Oral and Maxillofacial Implants*,[1] an attachment system is "a design of a particular type of retentive mechanism employing compatible matrix and patrix corresponding components. Matrix refers to the receptacle component of the attachment system, and patrix refers to the portion that has a frictional fit and engages the matrix."

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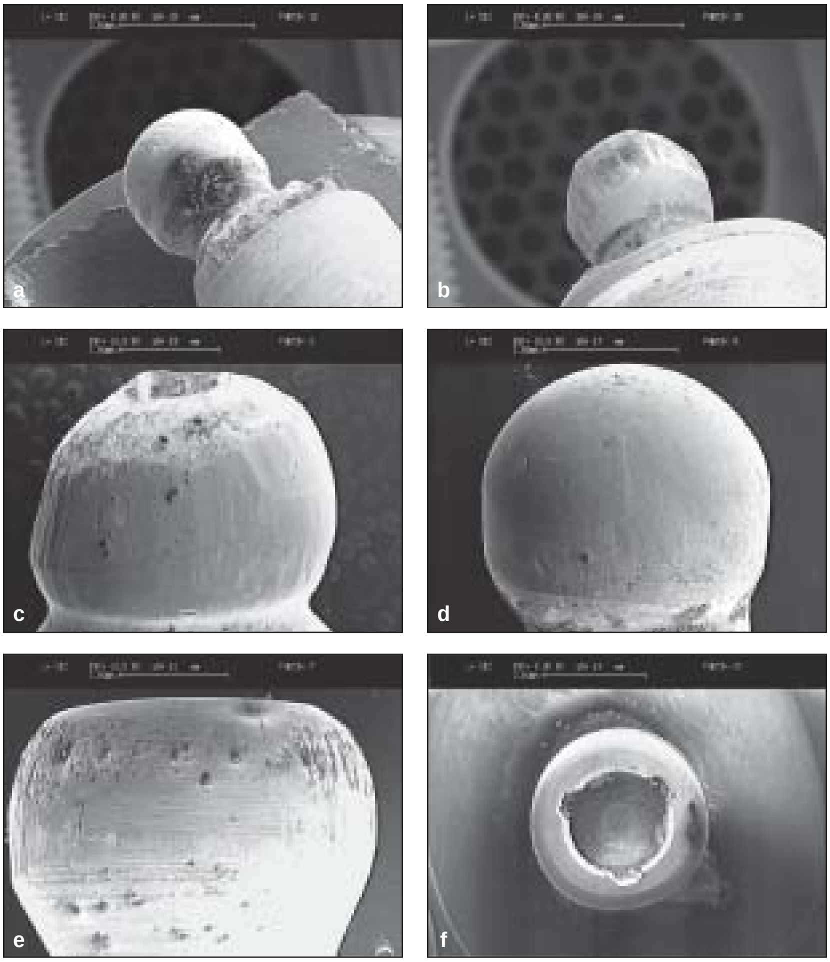
Attachment systems have been historically employed as a means of improving the retention and stability of tooth-supported overdentures in edentulous or nearly edentulous arches.[2–5] In recent years, these attachment systems have been successfully used with removable implant overdentures. The implants can be splinted together with bars or unsplinted with individual attachments of differing designs. Bar attachments and bar units for implant overdentures have evolved from the early 1960s.[5,6] The complexity of both bar attachments and bar units, with resilient or rigid designs based on the geometry of the bar and the number of implants employed,[7] has influenced their widespread acceptance.

On the other hand, the simplicity of attachment systems on unsplinted implants has made them widely used, particularly with mandibular implant overdentures.[5] They encompass ball, magnetic, and telescopic attachments. The retention of these attachments is

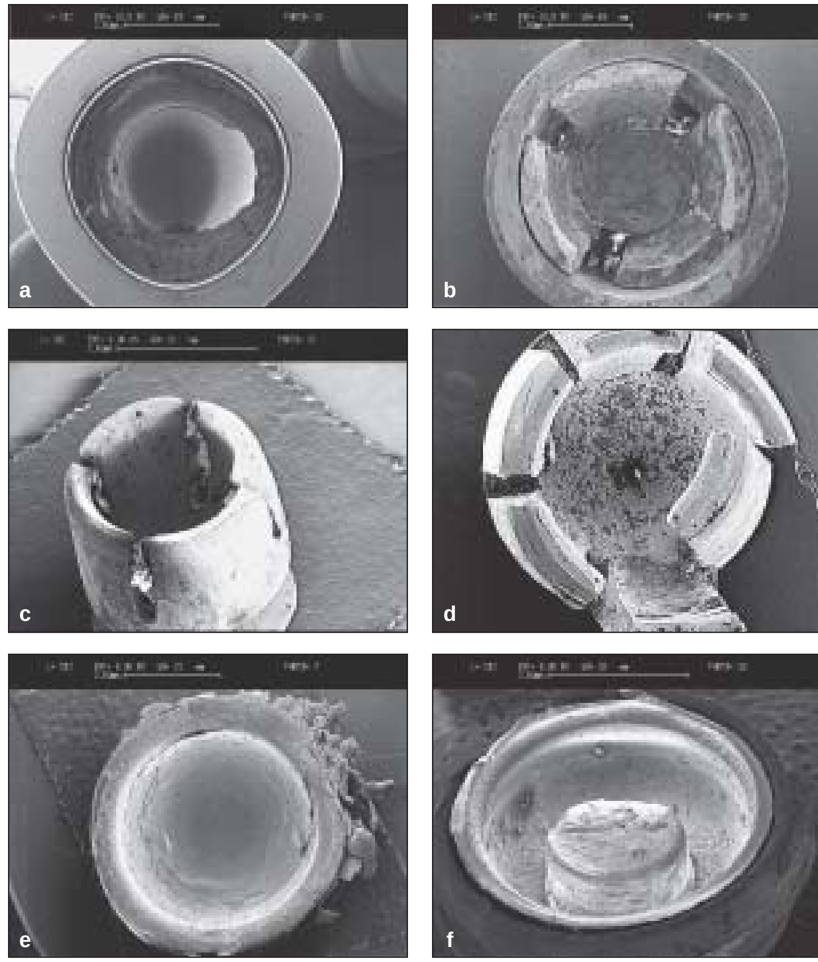


Figs 1a to 1f Scanning electron microscopic images (magnification ×15) of metallic patrices from different attachment systems exhibiting wear changes characterized by moderate **(a, d, e, f)** to extensive **(b, c)** material loss. **(a)** Titanium ball patrix 2.25 mm (Straumann Institute), **(b)** gold ball patrix 2.25 mm (Nobel Biocare), **(c)** gold ball patrix 3.50 mm (Nobel Biocare), **(d)** titanium ball patrix 2.25 mm (Southern Implants), **(e)** titanium with titanium nitride–coated ball patrix 3.95 mm (Southern Implants), and **(f)** titanium with titanium nitride–coated Locator abutment (Zest Anchors).

gained through mechanical interlocking, frictional contact, or magnetic forces of attraction between the patrices and matrices.[5,8,9] Ball attachments are considered the simplest type of attachments for clinical application with tooth- or implant-supported overdentures.[5] While considered generally resilient, the specific design of the ball attachment may influence the amount of its free movement, thereby limiting its resiliency.[10] Magnetic attachments have evolved over the years to become an additional option also available for use with mandibular implant overdentures. The development of closed-field magnets of rare earth alloys cobalt-samarium, and later neodymium-iron-boron, substantiated magnets as an optional overdenture attachment system.[11,12] A recent addition to the array of unsplinted attachment systems are the telescopic attachments. The attachment assembly is made up of a primary coping (patrix) attached to the implant and a secondary coping (matrix) that is contained within the overdenture framework.[9,13] The attachment can be of rigid or resilient design depending on the degree of fit between the two copings.[13] Similar to the majority of ball attachments, the retention of a telescopic attachment system is also obtained through the frictional contact between its components.

One current treatment option for the edentulous mandible with a removable prosthesis (when opposing a complete maxillary denture) is the placement of two splinted or unsplinted implants with the respective attachment system to support and retain an overdenture.[14] As a result, a plethora of attachment systems for mandibular two-implant overdentures is currently available and more are being produced by implant manufacturers, often without evidence-based support for their design, material selection, or long-term maintenance or repair. It is only when failure of attachment systems occur under clinical[15–17] or simulated function[18,19] that the modification or withdrawal of these attachments may take place.

Clinicians often base their selection of attachment system for mandibular implant overdentures empirically on their presumed retentive qualities. This is evident in the mandibular implant overdenture literature, where adequate retention has been correlated with improved levels of patient satisfaction.[20,21] Unfortunately, a definition as to what is an "acceptable"



Figs 2a to 2f Scanning electron microscopic images (magnification ×15) of matrices from different attachment systems exhibiting wear changes characterized by deterioration and deformation of polymeric **(a, e, f)** and metallic **(c, b, d)** matrices. **(a)** Rubber O-ring matrix in plastic housing (Nobel Biocare), **(b)** adjustable gold matrix (Nobel Biocare), **(c)** gold-palladium matrix (AlphaDent NV and Southern Implants), **(d)** gold matrix (Nobel Biocare), **(e)** plastic pink cap (Southern Implants), and **(f)** Locator nylon male insert (Zest Anchors).

level of retention for an attachment system is elusive in the literature. Early evidence from in vitro investigations on traditional tooth-supported overdentures suggested that 4 N could be the minimum retentive force expected from a single individual unsplinted attachment.[22,23] This was also empirically proposed in an extrapolation of retention gained from traditional clasp-retained partial dentures.[23] Furthermore, it was then suggested that an attachment system must be able to maintain its retentive force during a proposed lifespan of 10 years.[22] Evidence from past and current literature in some in vitro studies, however, indicates that attachment systems inevitably undergo wear-induced structural changes leading to a reduction or total loss of their retention. Both deterioration and deformation[24,25] along with work hardening lead to the eventual fracture of attachment components.[26] These events seem to occur with attachment systems of varied materials and designs (Figs 1 and 2).

Wear is defined as a “loss of material from a surface caused by a mechanical action alone or through a combination of chemical and mechanical actions.”[27] The mechanisms involved in the surface changes of attachment systems are complex and thought to result from tribochemic reaction, abrasion, adhesion, or surface disruption.[18] The variations in the extent of wear patterns seen with different attachment systems appear to be poorly understood. They remain merely speculative, based on the observed loss of retentive force under simulated wear tests.

The aim of this study was to review the literature on in vitro research investigating the retentive force or wear features of different attachment systems specifically for mandibular two-implant overdentures using an unsplinted prosthodontic design.

Materials and Methods

The search strategy involved an electronic search through the databases of PubMed, Embase, and Medline. Boolean operators were used to combine the following keywords: “retention,” “wear,” “overdenture attachments,” “attachment systems,” “implant-retained overdentures,” and “implant-supported overdentures.” The aim was to identify all articles reporting on in vitro investigations of retention or wear of attachment

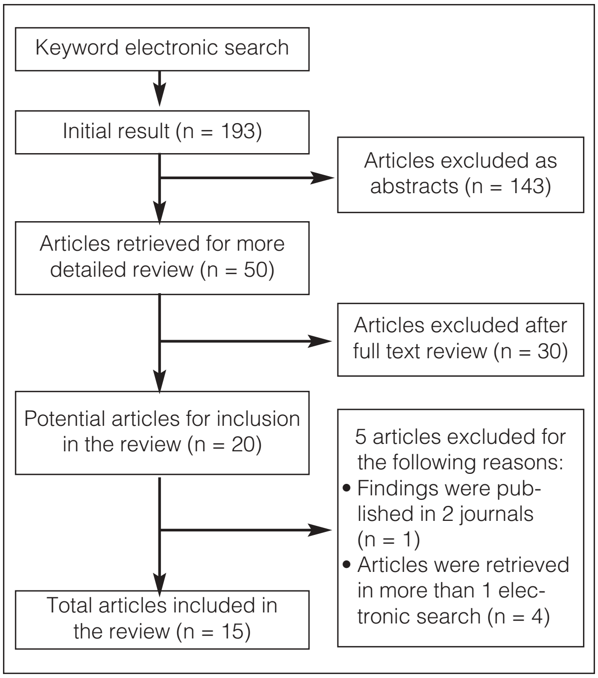


Fig 3 Schematic representation of the search strategy used in the review.

systems used specifically for mandibular two-implant overdentures. The search included articles published up to October 2008 and was limited to articles written in English that contained all or part of the key words in their headings. The electronic search was supplemented by hand-searching through the following journals: *Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, Implant Dentistry, International Journal of Oral and Maxillofacial Implants, International Journal of Oral and Maxillofacial Surgery, International Journal of Periodontics and Restorative Dentistry, International Journal of Prosthodontics, Journal of Clinical Periodontology, Journal of Dental Research, Journal of Oral Implantology, Journal of Oral and Maxillofacial Surgery, Journal of Periodontology, Journal of Prosthodontics,* and the *Journal of Prosthetic Dentistry.* The titles and abstracts of all articles were reviewed independently by the first two authors. Upon identification of a possible abstract for inclusion, the full text of the article was reviewed and cross-matched against the predefined inclusion criteria set by the authors. Any disagreement was resolved by discussion, and a third review author was consulted when necessary.

The inclusion criteria set for this review required articles to be primarily reporting on retention or wear features of attachment systems specifically for use with mandibular two-implant overdentures under in vitro conditions. Articles meeting these criteria were included regardless of the methodology used in evaluating the attachment systems.

For uniformity purposes in this review, the term "unsplinted attachments" was used to describe two freestanding or unconnected attachments. Accordingly, ball attachments, magnetic attachments, and telescopic copings were included under this term. Retentive force values were reported in Newtons regardless of the force unit used in the original article.

Results

The electronic search initially retrieved a total of 193 articles. Based on analysis of titles, abstracts, full-text contents, and cross-matching against the predefined inclusion criteria, 178 articles were excluded, leaving only 15 articles eligible for inclusion in this review (Fig 3). Searching by hand did not provide any further articles and therefore, only the 15 articles from the electronic search were considered.[9,10,19,24,25,28–37] Of the articles included, 6 provided information on only the initial retentive force of attachment systems for mandibular two-implant overdentures.[29,31–34,37] Eight more articles provided recording of the retentive force initially as well as under wear simulation tests.[9,19,24,25,28,30,35,36] Additionally, a single article[10] presented its findings based on a subjective evaluation of the retention quality of attachment systems without recording actual retentive force values. The findings extracted from these 15 articles were grouped under two main subheadings: retentive force determination for attachment systems and retentive force changes under simulated function.

Retentive Force Determination for Attachment Systems

Several investigations were conducted to determine the initial retentive force of a large array of commercially available attachment systems for mandibular two-implant overdentures.[29,31–34,37] Common themes among these studies were that the attachment systems were always investigated in pairs resembling actual mandibular two-implant overdenture scenarios, but under dry testing conditions. Conversely, variability was also evident among these studies relevant to the direction of the applied forces, the cross-head speed of the testing apparatus, the distance separating the two attachments, and the axial orientation of the attachment assembly to the supporting implants. Given these variables, it is not surprising that the findings were often contradictory even for similar attachment systems. Moreover, wide variations in the overall range of retentive forces reported for these attachment systems were also evident (Table 1).

In an earlier study, Petropoulos et al[34] investigated the retentive force of four unsplinted attachment systems. A single test model was constructed by embedding two

Table 1 Attachment Systems for Mandibular Two-Implant Overdentures: Initial Retentive Force Values

Study	System manufacturer	Attachment system	Material: Patrix	Material: Matrix	Test parameters: Cross-head speed	Test parameters: Direction of forces	Retentive force (N)
Chung et al[29]	Sterngold	ERA white	NA	NA	50 mm/min	Axial	23.76
		ERA grey	NA	NA	50 mm/min	Axial	35.24
	Zest Anchors	Locator white	NA	NA	50 mm/min	Axial	28.95
		Locator pink	NA	NA	50 mm/min	Axial	12.33
	Preat	Ball (Spheroflex)	NA	NA	50 mm/min	Axial	27.34
		Magnets (Shiner SR)	NA	NA	50 mm/min	Axial	3.88
	Aichi Steel	Magnets (Magnedisc 800)	NA	NA	50 mm/min	Axial	3.69
	Golden Dental Products	Magnets (Maxi 2)	NA	NA	50 mm/min	Axial	3.68
Gulizio et al[31]	Straumann	Ball	Titanium	Gold	2 mm/sec	Axial at 0 deg, 10 deg, 20 deg, and 30 deg angulation	23.8 overall mean at all angulations
	Cendres + Métaux	Ball	Titanium	Titanium	2 mm/sec	Axial at 0 deg, 10 deg, 20 deg, and 30 deg angulation	19.4 overall mean at all angulations
Michelinakis et al[32]	Astra Tech	Ball	Titanium	Gold	50 mm/min	Axial at interimplant distance:	
						19 mm	34.56
						23 mm	36.99
						29 mm	40.44
	Aichi Steel	Magnets (Magfit IP-AD)	Stainless steel	Nd-Fe-B	50 mm/min	Axial at inter-implant distance:	
						19 mm	1.23
						23 mm	1.13
						29 mm	1.29
Petropoulos and Smith[33]	Nobel Biocare	Ball 3.5 mm diameter	Gold	Rubber	50.8 mm/min	Axial	24.3
						Oblique	20.0
						Anteroposterior	34.6
		Ball 2.25 mm diameter	Titanium	Titanium alloy	50.8 mm/min	Axial	17.8
						Oblique	19.1
						Anteroposterior	32.9
	Zest Anchors	Zest Anchor Advanced Generation (ZAAG)	Nylon	Stainless steel gold plated	50.8 mm/min	Axial	37.2
						Oblique	27.2
						Anteroposterior	15.5
		Zest Anchor	Nylon	Stainless steel gold plated	50.8 mm/min	Axial	11.6
						Oblique	12.5
						Anteroposterior	5.2
	Sterngold	ERA orange	Nylon	Stainless steel Ti-N coated	50.8 mm/min	Axial	18.5
						Oblique	17.7
						Anteroposterior	8.6
		ERA white	Nylon	Stainless steel Ti-N coated	50.8 mm/min	Axial	12.7
						Oblique	12.3
						Anteroposterior	8.4
Petropoulos et al[34]	Sterngold	ERA grey	Nylon	Titanium, Ti-N coated	50.8 mm/min	Axial	7.18
						Oblique	19.2
	Zest Anchors	Zest Magnet	NA	NA	50.8 mm/min	Axial	1.25
						Oblique	1.40
		Zest Anchor	Nylon	Titanium, Ti-N coated	50.8 mm/min	Axial	5.59
						Oblique	5.30
	Nobel Biocare	Ball 3.5 mm diameter	Gold	Rubber	3 mm/min	Axial	2.39
						Oblique	2.75
Svetlize and Bodereau[37]	Dyna	Magnets-Dyna	NA	NA	3 mm/min	Axial	3.53
	Dentsply	Magnets-Shiner	NA	NA	3 mm/min	Axial	6.87
	Lifecore Biomedical	Ball (O-ring)	NA	NA	3 mm/min	Axial	11.07
		Ball (Dalla-Bona)	NA	NA	3 mm/min	Axial	22.7
	Ceka	Ball (Ceka Revax)	NA	NA	3 mm/min	Axial	21.88
	Zest Anchors	Zest Anchor Advanced Generation (ZAAG)	NA	NA	3 mm/min	Axial	15.74

NA = not available.

Brånemark implants of 3.75 mm diameter (Nobel Biocare) in the canine areas. Patrices of the attachment systems to be investigated were then connected randomly to the two implants. Acrylic resin overdenture analogs containing the corresponding attachment matrices were constructed and fit over the test model. A tensile force was applied to each overdenture sample in two different directions (axial and then oblique) at a cross-head speed of 50.8 mm/min. An overall mean retentive force range of 1.25 N to 7.18 N was reported for these attachments. The highest retentive force in both directions was reported for the ERA grey attachment system (Sterngold). On the other hand, the Zest magnet (Zest Anchors) presented the lowest retentive force of only 1.25 N and 1.40 N in the axial and oblique directions, respectively. The Zest anchor attachment (Zest Anchor) had the second highest retentive force followed by the 3.5-mm diameter Nobel Biocare ball attachment system. No significant difference was observed between the ERA attachment and the Zest anchor under axially and obliquely directed forces. This was related to the similarity in design common to both attachment systems. When the Zest anchor and the 3.5-mm diameter Nobel Biocare ball attachments were reinvestigated under similar conditions and using a similar experimental design, higher retention values were reported.[33] The authors attributed this finding to the modifications of these attachments by their respective manufacturers. The 3.5-mm diameter Nobel Biocare ball attachment consistently had a higher retentive force compared to its successor, the smaller 2.25-mm diameter ball attachment from the same manufacturer. Attachments of similar designs (ERA orange, ERA white, and Zest anchor) however, were still comparable in their retentive force under the different directions.

Using a similar methodology previously described,[33,34] Chung et al[29] conducted an investigation on the retentive forces of seven commercially available ball and magnetic attachment systems. A retentive force ranging from 3.69 N to 35.24 N under axially directed dislodging forces was reported. The authors grouped the attachment systems investigated into four categories based on the significant differences in their mean retentive forces, with the ERA grey attachment system having the highest retentive force recording with 35.24 N. Magnetic attachments from three different manufacturers were the weakest, which confirms previous findings of Petropoulos et al[34] and Petropoulos and Smith.[33]

A single article[32] reported on the retentive force values for ball and magnetic attachments under axially directed forces with implants placed 19, 23, and 29 mm apart. Magnetic attachments, in agreement with previous reports, demonstrated significantly lower retentive force values at all instances compared to the ball attachments. Both attachments, however, achieved their highest retentive force at the 29-mm interimplant distance.

In contrast to the aforementioned studies where implants and attachment systems were always aligned vertically during the tensile testing, Gulizio et al[31] investigated the effect of implant angulation on the retentive force of two ball attachment systems from a single manufacturer (Straumann). Gold and titanium attachments were placed on the implants at 0-degree, 10-degree, 20-degree, and 30-degree angulations in relation to the vertical axis. The reported overall mean retentive force at all angulations for the gold and titanium ball attachments was 23.8 N and 19.4 N, respectively. Reduction in the retentive force for both attachments was observed with the increase in implant angulation from 0 degrees to 30 degrees. This was more significant with the gold ball attachment at the 30-degree angulation. It was further observed that while both attachments demonstrated loss of retention, the retention performance of the two attachments during the tensile test differed considerably. The titanium ball attachment exhibited extreme inconsistency and fluctuation in its retentive force compared to the more uniform performance of the gold ball attachment. The authors related this finding to the complex design of the titanium matrix made of a stainless steel metal spring contained within two titanium rings. This particular design has also been implicated in the loss of retention observed in a similar ball attachment system from another manufacturer (Cendres + Métaux). Fluctuation and subsequent breakage of the stainless steel metal spring of this attachment led to a reduction or total loss of its retentive force.[19]

Retentive Force Changes Under Simulated Function

A number of articles[9,19,24,25,28,30,35,36] investigated the effect of short- and long-term simulated function on the retentive force of attachment systems. These attachment systems were investigated either as individual (single) attachments[9,19,24,25] or in combination (paired)[28,30,35,36] with study designs that attempted to emulate the actual oral environment (Table 2). Common to all of these studies, the retentive forces of the attachment systems were initially determined under axially directed tensile forces. The attachments were then subjected to cyclic loading under either axial or paraxial forces in the range of 540 to 10,000 cycles of repeated insertion and removal. This range was thought to simulate 6 months to 9 years of clinical function on the assumption of three daily removals and insertions of the overdenture for hygienic purposes.[19] With the exception of two reports,[9,28] all findings demonstrated a common trend toward reduction or total loss in retentive force across the majority of the attachment systems (Table 2).

Gamborena et al[25] investigated the retentive force of four color-coded ERA attachments (Sterngold) both initially and up to 5,500 insertion–separation cycles, simulating 3 years of clinical function. The patrices and matrices were of plastic and metal composition, respectively. A mean retentive force range between 1.52 N and 2.52 N was reported at baseline for all four types of attachments. At the conclusion of the wear simulation test, a dramatic loss of retention was observed across all four types of attachments, with an overall loss of 85% to 88% of the initial retentive force. Upon microscopic measurement (Nikon Measurescope 20) the authors observed distinct wear patterns characterized by distortion of the plastic patrices. The metallic matrices, on the other hand, appeared unchanged. The wear-induced changes in the dimensions of the plastic patrices were thought to have caused the eventual loss of retention observed with these attachments. Similar observations were also reported with other attachment systems.[24] Investigators re-created the equivalent of 1 year of clinical usage on four ball attachment systems. These attachments were of metallic (titanium) and polymeric (plastic, rubber, and nylon) components from different manufacturers. At the conclusion of the wear test, a significant reduction in the retentive force between 14% and 80% was evident for all four types of attachments. The attachment components were then examined under a scanning electron microscope to delineate the wear patterns. In agreement with the findings of Gamborena et al,[25] it was observed that the metallic components of these attachments appeared unaffected, while the polymeric ones exhibited distinct structural changes characterized by deformation and deterioration. In an attempt to further quantify the wear changes observed under the scanning electron microscope, the authors measured the weight changes in the attachment components before and after wear simulation using a precision electronic scale (Sartorious 1712). However, analysis of the measurements did not reveal any significant change.[24]

Wear-induced changes in retentive force were also demonstrated with short-term simulated function.[30] Ball and magnetic attachments were aged under simulated oral conditions and periodically subjected to manual pulls equivalent to 6 months of function. The ball attachments were found to have lost between 32% and 50% of their initial retentive force. By contrast, magnetic attachments incurred a minimal reduction in retentive force of only 1.7% to 5.3%. This is despite the signs of corrosion observed microscopically within the stainless steel magnet case.

The loss of retention under wear simulation has also been reported in several other studies,[9,19,28,30,35,36] which, in contrast to the above, did not present any objective evaluation of the wear changes. The implication of wear was mainly described based on the reported loss of retentive force under cyclic loading. Wide ranges of retentive forces were demonstrated initially and after wear simulation in these reports. Moreover, variations in the retentive forces were evident even among samples of the same attachment systems.[19,30,36] This variation was reflected in the large standard deviations recorded in particular for ball attachments of varied designs. In contrast, magnetic attachments have been observed to have the smallest standard deviations,[30,36] in line with the consistent retentive forces reported for these attachments.

A different pattern of retentive force changes under wear simulation was evident in two reports.[9,28] Besimo et al,[9] when investigating the retentive force of five telescopic attachments made of different alloys (titanium, gold, and cobalt-chromium), observed a steady increase in the retentive force of these attachments under long-term simulated function equivalent to 9 years. The increase in the mean retentive force of these attachments was between 17.5% and 97.4% of their initial values. The authors related this increase in retentive force to the increased mechanical adaptation of the attachment components under cyclic loading. On the other hand, the large variation in the retentive force increase observed among the different attachments was related to the differences in the physical properties of their alloys. In another report,[28] an increase in the retentive force of two ball attachment systems (Conexao Prosthesis and Lifecore Biomedical) after 5 years of simulated function was also reported. The increase however was less significant and in the range of 5.7% to 12.8%. This was thought to result from abrasion and material degradation of the retentive components of these attachments under wear simulation. On the other hand, the overall mean retentive force difference between the two attachment systems before and after wear simulation was related to the differences in the dimensions of their patrices.

Discussion

This literature review has revealed a limited number of articles reporting on the retentive force or wear features of unsplinted attachment systems for mandibular two-implant overdentures. A wide range of retentive forces has been reported for a large number of attachment systems currently available. The outcomes from the different studies, however, were perplexed by the variability in the study designs and the problem of manufacturer modifications of the attachment systems.

Table 2 Attachment Systems for Mandibular Two-Implant Overdentures: Retentive Force Changes Under Simulated Function

			Material				Test parameters		Retentive force (N)	
Study	System manufacturer	Attachment system	Patrix	Matrix	Attachment configuration (single/paired)	Medium	No. of loading cycles	Direction of force	Initial	Final
Besimo et al[9]	Ha-Ti implant system	Telescopic	Titanium, 5.5-deg angle	Gold alloy	Single	Saliva substitute	10,000	Axial	0.55	0.66
	Cendres + Métaux	Telescopic	Titanium, 6.5-deg angle	Gold alloy	Single	Saliva substitute	10,000	Axial	0.52	0.78
	Krupp-Widia	Telescopic	Titanium, 5.5-deg angle	Co-Cr	Single	Saliva substitute	10,000	Axial	0.51	0.61
		Telescopic	Titanium, 6.5-deg angle	Co-Cr	Single	Saliva substitute	10,000	Axial	0.52	0.66
		Telescopic	Gold alloy, 5.5-deg angle	Gold alloy	Single	Saliva substitute	10,000	Axial	0.39	0.77
		Telescopic	Gold alloy, 6.5-deg angle	Gold alloy	Single	Saliva substitute	10,000	Axial	0.50	0.67
		Telescopic	Gold alloy, 5.5-deg angle	Co-Cr	Single	Saliva substitute	10,000	Axial	0.57	0.67
		Telescopic	Gold alloy, 6.5-deg angle	Co-Cr	Single	Saliva substitute	10,000	Axial	0.54	0.64
		Telescopic	Titanium, 6.5-deg angle	Titanium	Single	Saliva substitute	10,000	Axial	0.55	0.87
Besimo and Guarneri[19]	Cendres + Métaux	Ball (Dalla Bona)	NA	NA	Single	Saliva substitute	10,000	Axial	9.0	6.7
		Conod anchor	NA	NA	Single	Saliva substitute	10,000	Axial	6.22	4.08
		Cylinder anchor (Dalla Bona)	NA	NA	Single	Saliva substitute	10,000	Axial	8.38	7.04
		Gerber cylinder	NA	NA	Single	Saliva substitute	10,000	Axial	7.70	5.92
		Mini-Gerber cylinder	NA	NA	Single	Saliva substitute	10,000	Axial	8.52	5.26
	NA	Cylinder anchor (Fah)	NA	NA	Single	Saliva substitute	10,000	Axial	6.46	4.76
Fromentin et al[24]	Core-Vent, Paragon	Ball (TSIB-Spectra system)	Titanium alloy	Plastic	Single	Distilled water at 37°C	1,080	Axial	34.13	29.34
	Zest Anchor	ZAAG	Nylon	Titanium, Ti-N coated	Single	Distilled water at 37°C	1,080	Axial	18.0	3.55
	Metalor/Suissor	Ball (Supra-Snap)	Titanium alloy	Plastic	Single	Distilled water at 37°C	1,080	Axial	5.19	3.17
	Sterioss, Nobel Biocare	Ball attachment (O-ring)	Titanium alloy	Rubber	Single	Distilled water at 37°C	1,080	Axial	16.67	9.90
Gamborena et al[25]	Sterngold	ERA white	Plastic	Metal	Single	Water at 37°C	5,500	Axial	14.90	2.25
		ERA orange	Plastic	Metal	Single	Water at 37°C	5,500	Axial	24.70	2.74
		ERA blue	Plastic	Metal	Single	Water at 37°C	5,500	Axial	22.74	3.72
		ERA grey	Plastic	Metal	Single	Water at 37°C	5,500	Axial	24.02	3.43
Botega et al[28]	Lifecore Biomedical	Ball	Titanium	Rubber O-ring	Paired	Artificial saliva at 37°C	5,500	Axial	18.41	19.46
	Conexao Prosthesis System	Ball	Titanium	Rubber O-ring	Paired	Artificial saliva at 37°C	5,500	Axial	12.78	14.42
Doukas et al[30]	Astra Tech	Ball	Titanium	Gold	Paired	Distilled water at 37°C	540	Manual pull at inter-implant distance of:		
								19 mm	34.56	23.37
								23 mm	36.99	21.91
								29 mm	40.44	20.19
	Aichi Steel	Magnets	Stainless steel	Ne-Fe-B	Paired	Distilled water at 37°C	540	19 mm	1.23	1.21
								23 mm	1.13	1.07
								29 mm	1.29	1.26
Rutkunas et al[35]	Aichi Steel	Magnedisc 500	Stainless steel	Nd-Fe-B	*	Demineralized water at 37°C	800	Axial	4.5	**
								Anterior	6.7	
								Lateral	2.8	
								Posterior	1.0	
		Magfit EX 600W	Stainless steel	Nd-Fe-B	*	Demineralized water at 37°C	800	Axial	4.7	**
								Anterior	7.2	
								Lateral	3.3	
								Posterior	1.3	

Table 2 continued Attachment Systems for Mandibular Two-Implant Overdentures: Retentive Force Changes Under Simulated Function

Study	System manufacturer	Attachment system	Material: Patrix	Material: Matrix	Attachment configuration (single/paired)	Medium	Test parameters: No. of loading cycles	Test parameters: Direction of force	Retentive force (N): Initial	Retentive force (N): Final
Rutkunas et al[35] *(continued)*		Magfit RK (dome-shaped)	Stainless steel Ti-N coated	Nd-Fe-B	*	Demineralized water at 37°C	800	Axial	5.8	**
								Anterior	7.7	
								Lateral	4.1	
								Posterior	1.9	
	Hitachi Metals	Hyperslim 4013	XM27	Nd-Fe-B	*	Demineralized water at 37°C	800	Axial	4.9	**
								Anterior	7.8	
								Lateral	3.9	
								Posterior	1.5	
		Hyperslim 4513	XM27	Nd-Fe-B	*	Demineralized water at 37°C	800	Axial	5.6	**
								Anterior	10.6	
								Lateral	4.7	
								Posterior	1.7	
	Inoue Attachments	OP anchor #4	Gold alloy	Rubber ring	*	Demineralized water at 37°C	800	Axial	3.7	3.7
								Anterior	5.4	6.0
								Lateral	3.3	3.6
								Posterior	8.5	8.5
	Zest Anchors	Locator (pink)	Nylon	Stainless steel	*	Demineralized water at 37°C	800	Axial	10.6	8.0
								Anterior	14.8	15.4
								Lateral	7.7	8.1
								Posterior	14.6	15.8
	Sterngold	ERA white	Nylon	Gold alloy	*	Demineralized water at 37°C	800	Axial	9.9	5.3
								Anterior	14.5	8.6
								Lateral	8.9	5.6
								Posterior	15.4	12.8
		ERA orange	Nylon	Gold alloy	*	Demineralized water at 37°C	800	Axial	10.9	5.2
								Anterior	13.3	8.8
								Lateral	6.1	4.6
								Posterior	16.2	12.8
Setz et al[36]	Nobel Biocare	Ball	Gold	Titanium	Paired	Water	15,000	Axial	~28	~8
		Ball	Gold	Gold	Paired	Water	15,000	Axial	~28	~22
		Ball	Gold	Rubber O-ring	Paired	Water	15,000	Axial	~9	~16
	Steco	Magnet (X-line)	Cobalt-Samarium	Cobalt-Samarium	Paired	Water	15,000	Axial	~3	~3
		Magnet (Z-line)	Cobalt-Samarium	Cobalt-Samarium	Paired	Water	15,000	Axial	~5	~5
	Biomet 3i	Ball (O-ring)	Titanium	Rubber	Paired	Water	15,000	Axial	~18	~2
		Ball (Dal-Ro)	Titanium	Gold	Paired	Water	15,000	Axial	~85	~78
	Straumann	Ball	Titanium	Gold	Paired	Water	15,000	Axial	~80	~75
	Friatec	Ball	Titanium	Gold	Paired	Water	15,000	Axial	~65	~85

NA = not available.
*Wear simulation under axial directions was conducted on single attachments, while that under rotational directions was performed on paired attachments.
**Magnetic attachments were not subjected to wear tests based on findings from preliminary investigations conducted on sample attachment that showed insignificant wear changes in retention force.

These were the compounding variables, making valid comparisons in the retention quality of these attachment systems and their behavior under wear simulation a difficult task. A common theme was that loss of retentive force under simulated function was an inevitable occurrence over time for the majority of attachment systems. Wear-induced changes within the attachment components were implicated as the primary etiologic factor for the loss of retention.[19,24,25,30,35,36] Even with the unexpected increase in the retentive force observed with certain attachment systems,[9,28] wear-induced changes were still implicated as the causative factor. The mechanisms of wear responsible for the variations in the retentive force changes observed with the different attachment systems under simulated function remain poorly understood.

Several factors were implied to influence the retentive force of attachment systems and their wear features under simulated function. Some of these factors were investigated as primary objective measures to determine their influence on the outcome (ie, implant angulation,[10,31] interimplant distance,[30,32] and the direction of applied dislodging forces[33–35]). Others, however, were only elucidated to have exerted their proposed influence merely based on the retentive force performance of the attachment systems (ie, material,[19,30,36] design,[10,19,31] dimension,[28,33] and mode of retention of attachment systems[30,32,35,36]). These factors merit discussion to ascertain the significance of their implied influence on the retention and wear of attachment systems and their relevance to clinical situations. It should be noted that with the intricate relationship between these factors, their impact must be considered within the confines of the individual studies where the attachment systems were investigated under identical conditions.

Influence of Attachment Material

Material selection for attachment systems should ideally allow for provision of adequate retention under long-term function. Preference for certain material combinations in attachment systems based on the reviewed literature remains inconclusive. The findings from the two reports[24,25] where an objective assessment of wear changes was attempted implied that polymeric (plastic, nylon, and rubber) components of attachment systems were more susceptible to wear than metallic ones. The structural changes observed in these components have been previously described to result from thermal expansion under cyclic loading in wet conditions.[38] The failure to demonstrate wear changes within the metallic components, however, could be related to either the minute magnitude of these changes or the limitations of the investigative methods employed.[24,25] Attachment systems of purely metallic components were indeed demonstrated to endure retention loss subsequent to wear simulation in several reports (albeit without an objective assessment of this loss).[19,30,36] Furthermore, physical properties of attachment alloys (modulus of elasticity in particular) were said to modulate the wear behavior of these attachments.[9]

Influence of Attachment Design

Poor retentive force performance of certain attachment designs (titanium matrices with stainless steel metal springs) was reflected by significant fluctuations and a subsequent loss of retention.[19,31] These findings were in accordance with those reported in several clinical studies using this particular attachment design where substantial maintenance was needed.[16,17] Hence, authors suggest that attachment systems must ideally be of a simple design and preferably made of as few components as possible, particularly in their retentive elements.[31] This was thought to ensure consistent and predictable retention. Of equal clinical benefit is that ball attachments designed with matrices capable of free rotation over the patrices (eg, Straumann retentive anchors and ball attachments from Nobel Biocare and Astra Tech) were found to be tolerant to implant malalignment.[10] The free movement of these matrices allows for their parallel alignment in relation to each other within the denture base and to the path of insertion and removal, irrespective of implant parallelism to certain extents.[10] Ball attachments with parallel-walled patrices, those with locking systems, and others with matrices engaging deep undercuts would conversely provide only limited flexibility. However, the ability of these attachment designs to sustain long-term adequate retention on nonparallel implants has not been investigated in the current literature.

Influence of Attachment Dimensions

Ball attachments with larger patrices were found to achieve higher retentive forces compared to similar attachments of smaller dimensions.[28,33] The rationale could be related to the increased surface area available for increased frictional contact between the patrices and matrices of these attachments.[28] Other unsplinted attachment systems used a similar concept in producing patrices with successive increasing dimensions to provide variable retentive forces (ERA, Sterngold and Locator attachments, Zest Anchor). The nylon patrices of these attachments are color-coded with each color representing a different level of retention based on the incremental increase in their dimensions. However, the ability to maintain this variable retention under simulated function was questionable.[25,35] Undoubtedly though, the ease by which worn patrices of these attachments (usually contained within a metal housing) can be replaced chairside is of valid clinical benefit.

Implant Angulation and Interimplant Distance

The retentive force of ball attachments was found to decrease with an increase in implant angulation. Optimum retentive force would therefore be expected with the attachments in a vertical alignment to the implants.[31] A 30-degree implant angulation was reflected in a reduction in the retentive force up to 25%. The authors argued, however, that this reduction is of little clinical significance and does not warrant the use of other means of retention to circumvent implant malalignment. Others demonstrated that with implants diverged up to 60 degrees, ball attachments can still provide adequate retention.[10] It should be noted here that the authors did not conduct retentive force recordings in their study, and the retention of these attachments at this angulation was only assessed subjectively by exerting manual pulls.

Another aspect of clinical relevance was the effect of the interimplant distance on the retentive force of ball and magnetic attachments. While the highest retentive force for both attachment systems was reported at the 29-mm interimplant distance, placing the implants at a shorter distance of 23 or 19 mm did not significantly affect the retentive force of these attachments.[30,32] The clinical benefits of these findings[10,30–32] are readily evident since implant parallelism at an optimum distance across the residual ridge cannot be consistently ensured. Hence, attachment systems tolerant of implant angulation and the variations in interimplant distance would certainly be of a clinical advantage.

Direction of the Dislodging Forces

Ball attachments generally achieve significantly higher retentive forces compared to magnetic attachments under either axially or paraxially dislodging forces.[29,30,32,34–37] Findings from comparative retentive force investigations on ball and magnetic attachments under multiple directions failed to draw a valid correlation (common to both attachment systems) between the retentive force and the direction of the dislodging forces.[33–35] Magnetic attachments reflected a tendency to exert maximum retention when dislodged from the anterior direction.[35] Their weakest retention has always been recorded under posteriorly directed forces. In contrast, a common trend to achieve a definite retention profile (increased or decreased retention) in a particular direction could not be established for the ball attachments.[33–35] This could be explained by the large variation in design, material, and mode of retention among these attachments. However, when similarities did exist, comparable retentive forces under different directions were evident in some reports.[33,34] The clinical relevance of recording the retentive force of attachments systems under paraxial dislodging forces was considered to be a measure of the stability of the overdenture.[33–35] The findings here implied that better stability for the overdenture would be expected from ball attachments compared to magnetic.

Mode of Retention

The findings from comparative studies on the retentive force of ball and magnetic attachments identified the latter as the weaker attachment system.[29,30,32,34,36,37] Despite this, magnetic attachments reflected a tendency to relatively maintain a reproducible and consistent retentive force under wear simulation.[30,32,35,36] This has been attributed largely to their inherent mode of retention being magnetic rather than frictional or mechanical.[30,34] Degradation of magnetic forces of attraction subsequent to corrosion and abrasion has been rarely described under in vitro conditions.[30] This could be due to the limitations of these in vitro investigations in depicting complex oral conditions.[29,35,36] Further, clinical studies have commonly implicated corrosion and abrasion in the short service life of magnetic attachments.[39,40] The weak retentive force currently reported for these attachments limits their clinical application to the less demanding situations common to elderly and medically compromised patients.[29,33]

A finding with this review worthy of consideration was the reported large variation in the retentive forces among samples of the same attachment system.[19,36] Authors related this occurrence to the poor quality control during the manufacturing process of attachment components.[36] Indeed, variations in the dimensions of the ball attachments of one system has been previously reported.[31] Manufacturers usually acknowledge minute variations in dimensions or material composition between the different patches of their products. The impact of these variations (when present) on the findings reported in this review and their clinical implications cannot be ascertained.

Conclusions

Within the limitations of this review, it was found that attachment systems for mandibular two-implant overdentures undergo wear-related changes leading to a reduction or loss of retention under simulated wear tests. The mechanism of wear that modulates the retentive force and wear features of the different attachment systems remains poorly understood and needs further research. Factors related to the material composition, design, dimensions, and the mode of retention of attachment systems have been implied to influence the retention and wear features of these attachments. However, their precise role remains inconclusive in the current literature. Further in vitro investigations of the factors involved in the retention and wear of attachment systems for mandibular two-implant overdentures are still needed. These factors should be investigated separately under well-controlled conditions to limit the influence of confounding variables on their outcome.

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