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REVIEW ARTICLE

Stud attachments for the mandibular implant-retained overdentures: Prosthetic complications. A literature review

Elie E. Daou *

Removable Prosthodontics Department, School of Dentistry, Lebanese University, Beirut, Lebanon

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Abstract A plethora of attachment systems for mandibular two-implant overdentures is currently available often without evidence-based support. Technical aspects are now parameters considered when choosing the appropriate attachment. Despite the increasing use of the Locator attachments, studies regarding their properties remain scarce. Peer reviewed articles published in English up to 2011, were identified through a MEDLINE search (Pubmed and Elsevier) and a hand search of relevant textbooks and annual publications. Emphasis was made on the technical complications as well as the loss of retention related to the attachments in implant-retained overdentures, primarily the Locator attachment. The evaluation of the long-term outcome of implant overdentures and complications associated with different attachment systems may provide useful guidelines for the clinician in selecting the type of attachment system and overdenture design.

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* Tel.: +961 3625049/ +961 9440445(Office).
E-mail addresses: dreliedaou@yahoo.com, eliedaou@hotmail.com.

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1. Introduction

The attachment mechanism in the implant overdenture (IOVD) provides enhanced retention and stability compared to the conventional denture (Klemetti, 2008; Burns et al., 1995). The support is gained from both the intraoral tissues and dental implants (Simon, 2003). The connection should minimize denture movement without increasing the stress on the implants (Tokuhisa and Koyano, 2003; Chung et al., 2004). Attachment systems are easy to use and many are currently available (Alsabeeha and Swain, 2009), with new types of connectors regularly being introduced to the market. The efficiency of ball and bar attachments is well-documented (Büttel and Marinello, 2009). However, some attachments are produced without evidence-based support for their long-term maintenance or repair, and the modification or withdrawal of these attachments may only take place after their failure (Besimo, 2003; Bayer et al., 2007).

Biological and technical complications may occur during implant therapy (Andreiotelli and Strub, 2010). Technical complications include mechanical damage to the implant and prosthetic components (Andreiotelli and Strub, 2010). Regardless of the anchorage system used, adjustments to the overdenture (OVD) attachment system are the most common mechanical problem in implant prosthodontics (Watson et al., 1997). Notably, Goodacre et al. studied trends in the incidence rates of complications among raw data from multiple sources. The loss of retention or adjustment of OVDs was the most commonly reported complication type (30%) (Goodacre et al., 2003). When selecting an attachment system, the clinician should consider guidelines regarding their long-term outcomes (Visser et al., 2006; Andreiotelli and Strub, 2010; Walton and Glick, 2002). Early clinical studies focused on the implant survival, but recent studies have considered prosthetic maintenance (i.e., adaption and repair capabilities) and have compared retention devices (Attard, 2004; Meijer et al., 2004). Although some debate exists regarding the retention durability of attachments (Sadowsky, 2001; Fromentin et al., 2011a), technical aspects are now considered to be part of the process of choosing an appropriate attachment (Büttel and Marinello, 2009).

In 2001, Zest Anchors (Escondido, CA, USA) introduced the Locator attachment, which provides an improved design that combines the best features of the ball, ERA (Sterngold), and cap attachment types (Schneider, 2001). The Locator device uses a dual retention approach and different retention values (Trakas et al., 2006; Evtimovska et al., 2009). It is classified as a resilient universal hinge, is indicated for limited interarch distances, and helps to correct interimplant angles of up to 40° (Nguyen et al., 2010). Although these attachments appear to function reasonably well, they lack long-term clinical evaluation (Cune et al., 2005; Visser et al., 2006; Kleis et al., 2010).

The retention value of the Locator attachment varies according to the color of the patrix (replaceable nylon insert) (Evtimovska et al., 2009). Despite their widespread use internationally, limited in vitro reports on the retentive force of these attachments are available. The cross-sectional strength of the Locator attachment is derived from its dual (inner and outer) retention characteristic (Chung et al., 2004; Rutkunas et al., 2007). The attachment uses mechanical and frictional retention modes (Alsabeeha and Swain, 2009; Alsabeeha et al., 2010) because the nylon male insert is slightly oversized compared to inner ring of the female abutment (Alsabeeha and Swain, 2009).

The outer margin simultaneously and completely engages the shallow undercut area at the outer margin of the abutment, while the central stud of the nylon male insert press-fits within the inner metal ring of the female abutment (Alsabeeha et al., 2010). Locator attachments are provided without an inner retention feature when they are aimed to correct implant angulation (Evtimovska et al., 2009).

The present review concerns technical complications and loss of retention related to attachments in mandibular implant-retained OVDs, primarily the Locator attachment. The aim was to help the pratician in IOVD attachment selection in his daily practice. An electronic search was conducted on PubMed, Medline, and Elsevier databases, by using the following keywords: "Locator," "complications," "retention," "wear," "overdenture attachments," "attachment systems," "implant-retained overdentures," and "implant-supported overdentures". Articles reporting on investigations of retention, wear, or complications of attachment systems used specifically for mandibular two-implant OVDs were identified. The search included English-language articles that were published through 2011. The electronic search was followed by hand searching through the available journals.

2. Literature review

2.1. "Acceptable" retention

The retentive force provided by an attachment system should be high enough to prevent displacement of the OVD (Setz and Engel, 1998). Clinicians often base their selection of attachment systems empirically on the presumed retentive qualities and levels of patient satisfaction offered by the system (Burns et al., 1995; Cune et al., 2005). However, a definition for what an "acceptable" level of retention is for an attachment system remains elusive (Alsabeeha and Payne, 2010), and manufacturers provide limited data about the retentive strength and wear of attachments (Pigozzo et al., 2009). For example, the minimum retentive force expected for a single individual unsplinted attachment might be 4 N (Lehmann, 1978; Chung et al., 2004). However, various retentive forces ranging from 1 to 85 N have been reported for different attachment systems in which the mandibular OVDs are retained by multiple implants (Chung et al., 2004; Petropoulos, 2002; Rutkunas et al., 2007; Alsabeeha and Payne, 2010). Although a rough estimate of 20 N of retentive force has been proposed to be adequate for mandibular two-implant OVDs (Setz and Engel, 1998), Pigozzo et al. noted that 5–7 N would stabilize an OVD (Pigozzo et al., 2009).

The retentive force is impacted by numerous features. For example, it may be gained from mechanical and frictional contacts or magnetic forces (Preiskel, 1996; Besimo, 2003; Laney et al., 2007). The interimplant distance can also affect the initial retention of some attachments (Michelinakis and Smith, 2006; Doukas et al., 2008). For an OVD supported by two implants, although the highest retentive force was reported at an interimplant distance of 29 mm, a significant change was not achieved when the implants were placed at a shorter distance of 23 or 19 mm (Michelinakis and Smith, 2006; Doukas et al., 2008).

Gulizio et al. and others noted a reduction in the retentive force for attachments when the implant angulation was increased from 0 to 30 degrees (Wiemeyer and Kazemi, 2001; Gulizio et al., 2005a,b). Increased implant angulation has been reported to reduce the longevity of the attachment retention (Al-Ghafli et al., 2009), by causing premature wear of the components and increased maintenance (Ortegón et al., 2009). Nonetheless, many spherical attachment systems may function appropriately when the implants lack parallelism, particularly if the matrix components in the prosthesis are positioned parallel to the vertical reference plane and to the path of withdrawal of the prosthesis (Wiemeyer and Kazemi, 2001; Gulizio et al., 2005b). Yang et al. observed that the retentive force was maintained until an inclination of 30 degrees when Locator blue or ball attachments were used (Yang et al., 2011). This tolerance in attachment systems could help in clinical cases, in which implant parallelism at an optimum distance across the residual ridge cannot be ensured (Wiemeyer and Kazemi, 2001; Gulizio et al., 2005a; Michelinakis and Smith, 2006; Doukas et al., 2008; Alsabeeha and Swain, 2009). However, patients still prefer attachments with superior stability (Kenny, 1998; Setz and Engel, 1998).

Another parameter that has obvious clinical implications in the retention and stability of the prosthesis during function is the release period, which is "the time required for the attachment system to lose retention or disengage from the abutment during forced separation" (Petropoulos and Kousvelari, 1997). Under excessive loads, an attachment system that readily disengages may protect the implants and the bone–implant interface from potentially harmful forces. Thus, the release period acts as a safety mechanism for the attachment (Chung et al., 2004). Similarly, the maximum dislodging force or peak load is an additional retention measurement. This parameter concerns "the maximum forces [that are] developed before complete separation of attachment components from teeth or implant abutments" (Botega et al., 2004). Because the loss of retention results from the wear of the attachments (Bayer et al., 2009), the number of insertion–removal cycles influences the maximum dislodging force (Wiemeyer and Kazemi, 2001; Bayer et al., 2009; Sadig, 2009).

Numerous studies have compared the retention characteristics of various OVD attachment systems. The type of connector has been shown to affect the retention and stability of IOVDs (Sadig, 2009). Attachment systems may be classified into four categories, from high to very low retention (Chung et al., 2004). Locator (Sadig, 2009) and Sterngold ERA attachments (Bonachela et al., 2003; Tabatabaian and Seyedan, 2010) provided significantly higher retention and stability of IOVDs compared to Nobel Biocare Ball connectors (Petropoulos and Kousvelari, 1997). Other studies confirmed these findings (Chung et al., 2004; Petropoulos, 2002), but Alsabeeha et al. reported that a prototype 7.9-mm and standard 2.25-mm ball attachment demonstrated higher retentive forces than the Locator white, pink, and blue connectors (Alsabeeha and Swain, 2009). The ZAAG attachment (Zest Anchor Advanced Generation) was more retentive for the peak load measurement than the Nobel Biocare ball, Zest Anchor, or Serngold ERA attachment (Petropoulos, 2002). When vertical and oblique functions were simulated by applying dislodging tensile forces, the ZAAG attachment was still the most retentive device. The Zest Anchor was the least retentive under vertical forces, and Nobel Biocare Standard was the least retentive under oblique retentive forces (Petropoulos, 2011).

2.2. Change of retentive values over time

It has been suggested that an attachment system must be able to maintain its retentive force during a proposed lifespan of 10 years (Lehmann, 1978). However, some in vitro studies have indicated that attachment systems inevitably undergo wear-induced structural changes, leading to a reduction or total loss of their retention. 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" (Anusavice, 1996). The wear of components of ball attachments was found to be responsible for a decrease in the retention of the attachments (Fromentin et al., 2011a). Deterioration, deformation (Fromentin and Tavernier, 1999), and work hardening may lead to the eventual fracture of the attachment components (Watkinson, 1987). Variations in the extent of wear patterns seen with different attachment systems remain speculative and poorly understood (Alsabeeha and Payne, 2010).

By using designs that attempted to emulate the actual oral environment, several studies (Besimo and Fluhrer, 1996; Setz and Engel, 1998; Fromentin and Tavernier, 1999; Besimo, 2003; Botega et al., 2004; Doukas et al., 2008; Rutkunas et al., 2007) investigated the effects of short-and long-term simulated function on the retentive forces of attachment systems. Retentive forces were initially determined under axially directed tensile forces, after which the systems were subjected to cyclic loading under axial or paraxial forces through 540–10,000 cycles of repeated insertion and removal. Given an assumption of three daily removals and insertions of the OVD for hygienic purposes, this range was thought to simulate 6 months to 9 years of clinical function (Besimo, 2003). Most of the attachment systems showed a common trend toward a reduction (Tabatabaian and Seyedan, 2010) or total loss in retentive force (Alsabeeha and Swain, 2009). Repeated insertion–removal cycles led to a gradual and continuous loss of retention of ball-socket attachments (Chung et al., 2004; Rutkunas et al., 2005; Evtimovska et al., 2009; Petropoulos, 2002). This loss was usually abrupt after approximately 500 cycles (Epstein et al., 1999) and reached as high as 80% of the initial value after 2000 cycles (Chung et al., 2004; Rutkunas et al., 2005; Evtimovska et al., 2009). Gamborena et al. noticed a dramatic loss of retention at the conclusion of the wear simulation test for ERA attachments. Microscopy measurements revealed distinct wear patterns characterized by the distortion of the plastic patrices, whereas the metallic matrices appeared unchanged (Gamborena et al., 1997). Similar observations were also reported with four ball-attachment systems (Fromentin and Tavernier, 1999; Barão et al., 2009).

Some studies have found that the diameters of ball abutments were reduced significantly after 1, 3, and 8 years of clinical wear, with a maximal amount of wear after 3 years of use (Fromentin et al., 2011a). Thus, severe mechanical wear on both surfaces may be noted after long periods of use (Fromentin et al., 2011b). Although some articles have noted smaller changes in the retention force when the attachment male and female components were of different material compositions (Bayer et al., 2011), others indicated that the ball attachments exhibited the highest wear when they were combined with a titanium matrix (Branchi et al., 2010). Researchers found evidence of variations in the retentive forces among samples of the same attachment systems (Setz and Engel, 1998; Besimo, 2003; Doukas et al., 2008). An adjustable attachment system has been proposed to compensate for wear and increase the retention force (Bayer et al., 2011).

Recent studies have compared the retention characteristics of the Locator attachment to those of other commonly used systems. Wear effects on OVD resilient attachments were studied by (Rutkunas et al. (2011). [Epub ahead of print]), who simulated 15,000 insertion–removal cycles on ERA orange and white (EO and EW), Locator pink, white, and blue (LRP, LRW and LRB), and OP anchor (OP) attachments. They used light microscopy and scanning electron microscopy (SEM) to evaluate dimensional changes and surface characteristics. The retentive force of the Locator attachments fluctuated throughout the wear-simulation period, whereas the retentive forces of the EO and EW attachments rapidly decreased.

The plastic cores were more damaged than the plastic rings of the attachment male parts (Rutkunas et al., 2011. [Epub ahead of print]). An SEM analysis showed smoother surfaces of some specimens after wear simulation (Fromentin and Tavernier, 1999). Other studies have confirmed this result for the ERA (Setz and Engel, 1998; Wichmann, 1999; Besimo, 2003). A literature review provided evidence of a reduction in the retentive force under in vitro conditions for most attachment systems (Alsabeeha and Swain, 2009).

Several in vitro studies have sought to determine the influence of mechanical fatigue on different IOVD attachments (Fromentin and Tavernier, 1999; Bayer et al., 2009). All of the attachment systems tested showed some retention loss during the experiment (Bonachela et al., 2003). However, according to Setz, even after 15,000 cycles, this loss was minimal when compared with the initial retentive forces (Setz and Engel, 1998). Evtimovska and others demonstrated that multiple pulls significantly reduced the retention of Locator attachments (Al-Ghafli et al., 2009; Evtimovska et al., 2009). In another study, simulated mastication reduced the retention of Locator attachments to 40% of the baseline value, with a nonlinear descending curve, but induced only minor changes in the retention of the ball attachment tested. The authors reported that the Locator nylon capsules were strongly affected and suggested that the maintenance needs were related to mastication (Abi Nader et al., 2011).

Twelve months after OVD delivery to patient, Kleis noticed damage in both of the male parts of the Locator group, which led to a 75.5% loss of retention and required a change of these parts (Kleis et al., 2010). Other researchers reported that nonparallel implants induce a more important reduction of the peak load-to-dislodgement (Evtimovska et al., 2009). Rutkunas reported that retention of OVD attachments became relatively stable after 800 cycles (Rutkunas et al., 2005), especially in the case of the most-retentive designs (Williams et al., 2001). Multiple placement–removal cycles of the OVD by the clinician before delivery were recommended (Kleis et al., 2010; Evtimovska et al., 2009). Nevertheless, Cakarer argued that the Locator system did not present any problem of retention when compared to ball and bar designs (Cakarer et al., 2011). The Locator root pink was the most retentive device after fatigue when compared to the Era orange and white systems, which retained less than 37% of their initial retention (Rutkunas et al., 2005).

Magnetic attachments experienced a minimal reduction in their retentive force (Doukas et al., 2008; Rutkunas et al., 2007) compared to the gradual decrease in the retention of stud attachments (Fakhry et al., 2010). Despite the signs of corrosion observed microscopically within the stainless steel magnet case, magnetic attachments showed less physical deterioration when tested under identical conditions (Rutkunas et al.,, 2005; Chung et al., 2011). In contrast, a steady increase in the retentive force of telescopic attachments made of different alloys (titanium, gold, and cobalt-chromium) was observed under long-term simulated function. The authors related this result to the increased mechanical adaptation of the attachment components under cyclic loading, with some variation related to the differences in the physical properties of the alloys (Besimo and Fluhrer, 1996; Botega et al., 2004).

2.3. Incidence of mechanical complications

Different studies have tried to identify or compare the etiological factors underlying the failure of splinting and unsplinting attachments. Bar or ball attachments have been considered comparable in terms of the reliability and the frequency of complications (Karabuda and Bayraktar, 2008; Cehreli et al., 2010b). Most investigations have indicated that the unsplinted design requires more prosthetic maintenance (Klemetti, 2008; Stoumpis, 2011; Cakarer et al., 2011). However, others noted that the maintenance frequency is slightly higher for the bar design (Gotfredsen, 2000; Mericske-Stern et al., 2009; Cakarer et al., 2011), with higher failure rates of bars with distal cantilever extensions (Waddell and Swain, 2006). No difference in the implant survival rate between attachment systems was reported by other reports (Bergendal, 1998; Cehreli et al., 2010a).

Studies have also sought to evaluate the incidence of mechanical complications of the Locator attachments compared to other commonly used OVD attachment systems. Cakarer et al. observed that the Locator was better in terms of maintenance frequency compared to ball or bar systems (Cakarer et al., 2011). Mackie et al. agreed that a higher prosthodontic success rate was achieved with the Locator compared to other attachments (Southern plastic and Straumann gold) over a 3-year period (Mackie et al., 2011). In contrast, Kleis et al. found that the Locator nylon matrices showed extensive deformation and deterioration, with a substantially higher need for maintenance, compared to ball attachments. Although the performance of the matrices was related to the creep response, that of the patrices was related to hardness (Kleis et al., 2010). Bilhan et al. found no correlation between the attachment type and the occurrence of complications (Bilhan et al., 2011), which was correlated with implant angulation (van Kampen et al., 2003).

2.4. Mastication and force distribution

Compared to insertion–removal cycles, mastication induces different patterns of wear and deformation of the attachment system. By displacing the mucosa under the denture base, occlusal loads provoke rotation of the denture around the attachments (Porter and Brunski, 2002). The degree of the occlusal load transmitted to the attachments is related to their resiliency (Mericske-Stern, 1998; Heckmann et al., 2001). An optimal stress distribution is required to reduce the forces on the implants and the denture movement (Tokuhisa and Koyano, 2003). Both (Cakarer et al. (2011)) and (Trakas et al. (2006)) noted that correct implant placement reduced the maintenance of attachment systems. To correct for a lack of proper occlusion and possible rotation of the denture around the retentive components, due to the inevitable continuous resorption of the underlying residual ridge, constant rebasing of implant-retained OVDs may be necessary (Chaldek, 2010; Polychronakis and Zissis, 2010).

Various other factors, such as the length, number, and angulation of the implants, the opposing dentition, and parafunctional habits, may increase the susceptibility to mechanical complications (Sones, 1989). In the severely resorbed mandible, implants supporting or retaining an OVD may be subjected to excessive masticatory forces, including off-axis centric contacts, excursive contacts, and cantilevered loading (Binon, 2000). In the case of angulated implants, the occlusal forces may generate more strain than the screw can bear (Rangert et al., 1995; Binon, 2000). A large variation in retentive forces was reported among samples of the same attachment system (Setz and Engel, 1998; Besimo, 2003). This finding may have been related to poor quality control during the manufacturing process of the attachment components (Setz and Engel, 1998), because differences in the dimensions or material composition have been found between different batches of the same product (Ortegón et al., 2009).

3. Discussion

Few in-depth studies and standardized criteria are available to compare different options for mandibular IOVD treatment (Attard, 2004; Meijer et al., 2004; Andreiotelli and Strub, 2010). In particular, Bryant et al. found that clinical studies with a similar study design that simultaneously evaluated all or most of the categories of complications were too rare to allow them to calculate an overall complication incidence for IOVDs (Bryant and Kim, 2007). Although accurate measurement devices have recently been developed, they only allow comparisons of attachments that work on similar bases (Fromentin et al., 2010 Chaldek, 2010).

A limitation of this literature review is that it included non-randomized controlled studies. In particular, some studies did not include significant sample size and precise and reproducible measurement methods, whereas other studies were in vitro experiments. The performance of in vitro studies cannot overcome the need for well-structured clinical prospective studies. In finite element analysis, the accuracy of the experiment relies on the parameters applied to the model, including the geometry, constraints, and mechanical properties (Saab et al., 2007). Masticatory loading submits OVDs to complex three-dimensional movements. The presence of saliva (Besimo, 2003; Botega et al., 2004), denture cleansers (Nguyen et al., 2010; You et al., 2011), and food particles (Cune et al., 2005) may influence the clinical wear. As a result, it is difficult to reproduce the oral environment in vitro. To limit the influence of confounding variables, factors must be investigated separately under well-controlled conditions (Alsabeeha and Swain, 2009), and the results should be interpreted carefully. Evidence-based studies do not permit us to determine the most effective connection between the OVD and the supporting implants, and some questions remain unanswered.

Ultimately, the goals when placing any connector should be minimal complications and an equally atraumatic distribution of forces between the mechanical and the biological supporting structures (Chung et al., 2004). The selection of an appropriate attachment by the clinician is inevitably based on empirical evidence, such as the amount of retention desired and the specific clinical situation (Petropoulos, 2002). However, the ability to maintain this retention under the simulated function remains questionable (Gamborena et al., 1997; Rutkunas et al., 2007). Measurement of the retention values at the beginning of the treatment and after function would help to provide treatment according to the individual needs of the patient (Naert et al., 1994). An annual follow-up would be necessary after the patient is given the Locator system (Kleis et al., 2010). In addition to scientific evidence related to the clinical performance of the implants and attachments, the objective oral function and the patients' appreciation of the treatment should guide the clinician in his or her ultimate choice of an attachment type. The initial and eventual costs of maintenance and repairs must also be considered (Cune et al., 2010). The clinician should consider that the provision of adequate aftercare may be difficult or impossible when treating aging patients, especially if they become dependent and frail (Rentsch-Kollar and Mericske-Stern, 2010).

4. Conclusion

Clinical publications comparing the maintenance of Locator attachment devices with other systems remain scarce (Andreiotelli and Strub, 2010). Well-designed studies examining the long-term behavior of these attachments are needed (Evtimovska et al., 2009), because variations in protocols preclude the proper analysis of certain complications (Andreiotelli and Strub, 2010). Nevertheless, the Locator system provides the dental practitioner with a useful attachment option for patients requiring an implant-retained OVD (Saha, 2009). Careful postinsertion maintenance of the prosthesis, the attachment system, and the mucosa is essential (Ichikawa et al., 1996). Out-of-pocket expenses for the initial treatment and for long-term maintenance are low (Carlsson et al., 2004), and the repair and replacement processes are not time-consuming (Chung et al., 2004; Chung et al 2004; Kleis et al., 2010).

References

Abi Nader, S.d.S.R., Fortin, D., De Koninck, L., Fromentin, O., Albuquerque Jr., R.F., 2011. Effect of simulated masticatory loading on the retention of stud attachments for implant overdentures. J. Oral Rehabil. 38 (3), 157–164.

Al-Ghafli, S.A.M.K.X., Hirayama, H., Kang, K., 2009. The in vitro effect of different implant angulations and cyclic dislodgement on the retentive properties of an overdenture attachment system. J. Prosthet. Dent. 102, 140–147.

Alsabeeha, N., Nabeel, H.M., Payne, A.G., 2010. ''Loading protocols for mandibular implant overdentures: a systematic review with meta-analysis.''. Clin. Implant Dent. Relat. Res. 12 (1), e-28–e-38.

Alsabeeha, N.A.M., Swain, M.V., Payne, A.G., 2010. Attachment systems for mandibular single-implant overdentures: an in vitro retention force investigation on different designs. Int. J. Prosthodont. 23 (2), 160–166.

Alsabeeha, N.H.P.A., Swain, M.V., 2009. Attachment systems for mandibular two-implant overdentures: a review of in vitro investigations on retention and wear features. Int. J. Prosthodont. 22 (5), 429–440.

Andreiotelli, M.A.W., Strub, J.-R., 2010. Prosthodontic complications with implant overdentures: a systematic literature review. Int. J. Prosthodont. 23, 195–203.

Anusavice, K.J., 1996. Phillips' Science of Dental Materials. WB Saunders, Philadelphia.

Attard, N.J.Z.G., 2004. Long-term treatment outcomes in edentulous patients with implant overdentures: the Toronto study. Int. J. Prosthodont. 17, 425–433.

Barão, V.A.A.W., Tabata, L.F., Delben, J.A., Gomes, E.A., de Sousa, E.A., Rocha, E.P., 2009. Finite element analysis to compare complete denture and implant-retained overdentures with different attachment systems. J. Craniofac. Surg. 20 (4), 1066–1071.

Bayer, S.G.n.M., Keilig, L., Hültenschmidt, R., Nicolay, C., Bourauel, C., et al, 2007. Investigation of the wear of prefabricated attachments – an in vitro study of retention forces and fitting tolerances. Quintessence Int. 38, 229–237.

Bayer, S.K.L., Kraus, D., Grüner, M., Stark, H., Mues, S., Enkling, N., 2011. Influence of the lubricant and the alloy on the wear behaviour of attachments. Gerodontology 28 (3), 221–226.

Bayer, S.S.D., Grüner, M., Keilig, L., Enkling, N., Stark, H., Mues, S., 2009. Comparative study of four retentive anchor systems for implant supported overdentures – retention force changes. Gerodontology 26 (4), 268–272.

Bergendal, T.E.B., 1998. Implant-supported overdentures: a longitudinal prospective study. Int. J. Oral Maxillofac. Implants 13 (2), 253–262.

Besimo, C.E.G.A., 2003. In vitro retention force changes of prefabricated attachments for overdentures. J. Oral Rehabil. 30, 671–678.

Besimo, C.E.G.G., Fluhrer, M., 1996. Retention force changes in implant-supported titanium telescope crowns over long-term use in vitro. J. Oral Rehabil. 23, 372–378.

Bilhan H., Geckili O., Mumcu E, Bilmenoglu C., 2001. ''Maintenance requirements associated with mandibular implant overdentures: clinical results after first year of service.'' J Oral Implantol 37(6), 697–704. [Epub ahead of print].

Binon, P.P., 2000. Implants and components: entering the new millennium. Int. J. Oral Maxillofac. Implants 15, 76–94.

Bonachela, W.C.P.A., Marins, L., Pereira, T., 2003. Comparative evaluation of retention loss in four types of attachments used on overdentures in function of time of use. J. Appl. Oral Sci. 11 (1), 49–54.

Botega, D.M.M.M., Henriques, G.E., Vaz, L.G., 2004. Retention force and fatigue strength of overdenture attachment systems. J. Oral Rehabil. 31, 884–889.

Branchi, R.V.D., Virga, A., Guertin, G., Fazi, G., 2010. Resistance to wear of four matrices with ball attachments for implant overdentures: a fatigue study. J. Prosthodont. 19 (8), 614–619.

Bryant, S.R., MacDonald-Jankowski, D., Kim, K., 2007. Does the type of implant prosthesis affect outcomes for the completely edentulous arch? Int. J. Oral Maxillofac. Implants 22 (Suppl.), 117–139.

Burns, D.R.U.J., Elswick Jr., R.K., Beck, D.A., 1995. Prospective clinical evaluation of mandibular implant overdentures. Part 1: retention, stability and tissue response. J. Prosthet. Dent. 73, 354-36.

Büttel, A.E.B.N., Marinello, C.P., 2009. Locator or ball attachment: a guide for clinical decision making. Schweiz. Monatsschr. Zahnmed. 119 (9), 901–918.

Cakarer, S.C.T., Yaltirik, M., Keskin, C., 2011. Complications associated with the ball, bar and Locator attachments for implant-supported overdentures. Med. Oral Patol. Oral Cir. Bucal. 16 (7), e953-9.

Carlsson, G.E.K.M., de Baat, C., et al, 2004. A survey of the use of mandibular implant overdentures in 10 countries. Int. J. Prosthodont. 17, 122–122.

Cehreli, M.C.K.D., Kökat, A.M., Akça, K., Eckert, S., 2010a. A systematic review of marginal bone loss around implants retaining or supporting overdentures. Int. J. Oral Maxillofac. Implants 25 (2), 266–277.

Cehreli, M.C.K.D., Kokat, A.M., Akca, K., Eckert, S.E., 2010b. Systematic review of prosthetic maintenance requirements for implant-supported overdentures. Int. J. Oral Maxillofac. Implants 25 (1), 163–180.

Chaldek, G.W.-W.M., 2010. The evaluation of selected attachment systems for implant-retained overdenture based on retention characteristics analysis. Acta Bioeng. Biomech. 12 (3), 75–83.

Chung, K.H.C.C., Cagna, D.R., Cronin Jr., R.J., 2004. Retention characteristics of attachment systems for implant overdentures. J. Prosthodont. 13 (4), 221–226.

Chung, K.H.W.D., Kronstrom, M., Chan, D., Wataha, J., 2011. Retentive characteristics of overdenture attachments during repeated dislodging and cyclic loading. Int. J. Prosthodont. 24 (2), 127–129.

Cune, M.B.M., van Kampen, F., de Putter, C., van der Bilt, A., 2010. Mandibular overdentures retained by two implants: 10-year results from a crossover clinical trial comparing ball-socket and bar-clip attachments. Int. J. Prosthodont. 23, 310–317.

Cune, M.v.K.F., van der Bilt Bosman F, A., Bosman, F., 2005. Patient satisfaction and preference with magnet, bar-clip, and ball-socket retained mandibular implant overdentures: a cross-over clinical trial. Int. J. Prosthodont. 18 (2), 99–105.

Doukas, D.M.G., Smith, P.W., Barclay, C.W., 2008. The influence of interimplant distance and attachment type on the retention characteristics of mandibular overdentures on 2 implants: 6-month fatigue retention values. Int. J. Prosthodont. 21 (2), 152–154.

Epstein, D.D.E.P., Cohen, B.I., Pagnillo, M.K., 1999. Comparison of the retentive properties of six prefabricated post overdenture attachment systems. J. Prosthet. Dent. 82, 925–984.

Evtimovska, E.M.R., Driscoll, C.F., Elaine Romberg, E., 2009. The change in retentive values of Locator Attachments and Hader clips over time. J. Prosthodont. 18, 479–483.

Fakhry, A.T.S., Heiner, A.D., Dehkordi-Vakil, F.H., Dircks, H.W., 2010. Methodology for measuring the in vitro seating and unseating forces of prefabricated attachment systems used to retain implant overdentures. J. Prosthodont. 19 (2), 87–94.

Fromentin, O.L.C., Abi Nader, S., Feine, J., de Albuquerque Junior, R.F., 2010. Testing the retention of attachments for implant overdentures–validation of an original force measurement system. J. Oral Rehabil. 37 (1), 54–62.

Fromentin, O.L.C., Nader, S.A., Feine, J., de Albuquerque Jr., R.F., 2011a. Clinical wear of overdenture ball attachments after 1, 3 and 8 years. Clin. Oral Implants Res. 22 (11), 1270–1274.

Fromentin, O.L.C., Nader, S.A., Feine, J., de Albuquerque Jr., R.F., 2011b. Wear of ball attachments after 1 to 8 years of clinical use: a qualitative analysis. Int. J. Prosthodont. 24 (3), 270–272.

Fromentin, O.P.B., Tavernier, B., 1999. In vitro study of the retention and mechanical fatigue behavior of four implant overdenture stud-type attachments. Pract. Periodontics Aesthet. Dent. 11 (3), 391–397.

Gamborena, J.I.H.L., NaBadalung, D., Brudvik, J., 1997. Retention of ERA direct overdenture attachments before and after fatigue loading. Int. J. Prosthodont. 10, 123–130.

Goodacre, C.J.B.G., Rungcharassaeng, K., Kan, J.Y., 2003. Clinical complications with implants and implant prostheses. J. Prosthet. Dent. 90, 121–132.
Gotfredsen, K.H.B., 2000. Implant-supported mandibular overdentures retained with ball or bar attachments: a randomized prospective 5-year study. Int. J. Prosthodont. 13 (2), 125–130.
Gulizio, M.P.A.J., Kelly, J.R., Taylor, T.D., 2005a. Effect of implant angulation upon retention of overdenture attachments. J. Prosthodont. 14 (1), 3–11.
Gulizio, M.P.A.J., Kelly, R.J., Taylor, T.D., 2005b. Effect of implant angulation upon retention of overdenture attachments. J. Prosthodont. 24, 6–22.
Heckmann, S.M.W.W., Meyer, M., Weber, H.P., Wichmann, M.G., 2001. Overdenture attachment selection and the loading of implant and denture-bearing area. Part 2: a methodical study using five types of attachment. Clin. Oral Implants Res. 12, 640–647.
Ichikawa, T.H.M., Wigianto, R., et al, 1996. In vitro study of mandibular implant-retained overdentures: the influence of stud attachments on load transfer to the implant and soft tissue. Int. J. Prosthodont. 9, 394–399.
Karabuda, C.Y.M., Bayraktar, M., 2008. A clinical comparison of prosthetic complications of implant-supported overdentures with different attachment systems. Implant Dent. 17 (1), 74–81.
Kenny, R.R.M., 1998. Photoelastic stress patterns produced by implant-retained overdentures. J. Prosthet. Dent. 80, 559–564.
Kleis, W.K.K.P.W., Hartmann, S., Al-Nawas, B., Wagner, W., 2010. A comparison of three different attachment systems for mandibular two-implant overdentures: one-year report. Clin. Implant Dent. Relat. Res. 12 (3), 209–218.
Klemetti, E., 2008. Is there a certain number of implants needed to retain an overdenture? J. Oral Rehabil. 35 (Suppl. 1), 80–84.
Laney, W.R., Broggini, N., Cochran, D.L., et al., 2007. Glossary of Oral and Maxillofacial Implants Berlin. Quintessence p199.
Lehmann, K.M.A.F., 1978. Studies on the retention forces of snap-on attachments. Quintessence Dent. Technol. 7, 45–48.
Mackie, A.L.K., Thomson, W.M., Payne, A.G., 2011. Mandibular two-implant overdentures: three-year prosthodontic maintenance using the locator attachment system. Int. J. Prosthodont. 24 (4), 328–331.
Meijer, H.J.R.G., Van't Hof, M.A., Visser, A., 2004. A controlled clinical trial of implant-retained mandibular overdentures: 10 years' results of clinical aspects and aftercare of IMZ implants and Brånemark implants. Clin. Oral Implants Res. 15, 421–427.
Mericske-Stern, R.P.D., Fahrländer, F., Schellenberg, M., 2009. Within-subject comparison of two rigid bar designs connecting two interforaminal implants: patients' satisfaction and prosthetic results. Clin. Implant Dent. Relat. Res. 11 (3), 228–237.
Mericske-Stern, R., 1998. Three-dimensional force measurements with mandibular overdentures connected to implants by all-shaped retentive anchors. A clinical study. Int. J. Oral Maxillofac. Implants 13, 36–43.
Michelinakis, G.B.C., Smith, P.W., 2006. The influence of interimplant distance and attachment type on the retention characteristics of mandibular overdentures on 2 implants: initial retention values. Int. J. Prosthodont. 19 (5), 507–512.
Naert, I.Q.M., Hooghe, M., van Steenberghe, D., 1994. A comparative prospective study of splinted and unsplinted Branemark implants in mandibular overdenture therapy: a preliminary report. J. Prosthet. Dent. 71, 486–492.
Nguyen, C.T.M.R., Driscoll, C.F., Romberg, E., 2010. The effect of denture cleansing solutions on the retention of pink Locator Attachments: an in vitro study. J. Prosthodont. 19 (3), 226–230.
Ortegón, S.M.T.G., Agar, J.R., Taylor, T.D., Perdikis, D., 2009. Retention forces of spherical attachments as a function of implant and matrix angulation in mandibular overdentures: an in vitro study. J. Prosthet. Dent. 101 (4), 231–238.
Petropoulos, V.C.M.F., 2011. Comparison of retention and strain energies of stud attachments for implant overdentures. J. Prosthodont. 20 (4), 286–293.
Petropoulos, V.C.S.W., 2002. Maximum dislodging forces of implant overdenture stud attachments. Int. J. Oral Maxillofac. Implants 17 (4), 526–535.
Petropoulos, V.C.S.W., Kousvelari, E., 1997. Comparison of retention and release periods for implant overdenture attachments. Int. J. Oral Maxillofac. Implants 12, 176–185.
Pigozzo, M.N.M.M., Henriques, G.E., Vaz, L.G., 2009. The service life of implant-retained overdenture attachment systems. J. Prosthet. Dent. 102 (2), 74–80.
Polychronakis, N.S.M., Zissis, A., 2010. A modified method for rebasing implant-retained overdentures. Int. J. Prosthodont. 23 (2), 152–154.
Porter Jr., J.A.P.V., Brunski, J.B., 2002. Comparison of load distribution for implant overdenture attachments. Int. J. Oral Maxillofac. Implants 17 (5), 651–662.
Preiskel, H., 1996. Overdentures made easy: a guide to implant and root supported prostheses. Quentessence, London.
Rangert, B., Langer B, K.P., Van Roekel, N., 1995. Bending overload and implant fracture: a retrospective clinical analysis. Int. J. Oral Maxillofac. Implants 10, 326–334.
Rentsch-Kollar, A.S.H.S., Mericske-Stern, R., 2010. Mandibular implant overdentures followed for over 10 years: patient compliance and prosthetic maintenance. Int. J. Prosthodont. 23, 91–98.
Rutkunas V., Mizutani H., Takahashi, H., Iwasaki, N., 2011. Wear simulation effects on overdenture stud attachments. Dent. Mater. J. [Epub ahead of print].
Rutkunas, V., Mizutani, H., Takahashi, H., 2007. Influence of attachment wear on retention of mandibular overdenture. J. Oral Rehabil. 34 (1), 41–51.
Rutkunas, V., Mizutani, H., Takahashi, H., 2005. Evaluation of stable retentive properties of overdenture attachments. Stomatologija 7 (4), 115–120.
Saab, X.E.G.J., Powers, J.M., et al, 2007. Effect of abutment angulation on the strain on the bone around an implant in the anterior maxilla: a finite element study. J. Prosthet. Dent. 92, 89-51.
Sadig, W., 2009. A comparative in vitro study on the retention and stability of implant-supported overdentures. Quintessence Int. 40 (4), 313–319.
Sadowsky, S.J., 2001. Mandibular implant-retained overdentures: a literature review. J. Prosthet. Dent. 86, 468–473.
Saha, S.R.-C.A., 2009. Mandibular implant-retained complete overdenture using retentive abutments: a case report. Dent. Update 36 (3), 154–158.
Schneider, A.L.K.G., 2001. Bar overdentures utilizing the locator attachment. Gen. Dent. 49 (2), 210–214.
Setz, I.L.S., Engel, E., 1998. Retention of prefabricated attachments for implant stabilized overdentures in the edentulous mandible: an in vitro study. J. Prosthet. Dent. 80 (3), 323–329.
Simon, H.Y.R., 2003. Terminology for implant prostheses. Int. J. Oral Maxillofac. Implants 18, 539–543.
Sones, A.D., 1989. Complications with osseointegrated implants. J. Prosthet. Dent. 62, 581–585.
Stoumpis, C.K.R., 2011. To splint or not to splint oral implants in the implant-supported overdenture therapy? A systematic literature review. J. Oral Rehabil. 38 (11), 857–869.
Tabatabaian, F.A.F., Seyedan, K., 2010. Comparison of three attachments in implant-tissue supported overdentures: an in vitro study. J. Dent. (Tehran) 7 (3), 226–228.
Tokuhisa, M.M.Y., Koyano, K., 2003. In vitro study of a mandibular implant overdenture retained with ball, magnet, or bar attachments: comparison of load transfer and denture stability. Int. J. Prosthodont. 16 (2), 128–134.
Trakas, T.M.K., Kang, K., Hirayama, H., 2006. Attachment systems for implant retained overdentures: a literature review. Implant Dent. 15 (1), 24–34.

van Kampen, F.C.M., van der Bilt, A., Bosnian, F., 2003. Retention and postinsertion maintenance of bar-clip, ball and magnet attachments in mandibular implant overdenture treatment: an in vivo comparison after 3 months of function. Clin. Oral Implants Res. 14, 720–726.

Visser, A.M.H., Raghoebar, G.M., Vissink, A., 2006. Implant-retained mandibular overdentures versus conventional dentures: 10 years of care and aftercare. Int. J. Prosthodont. 19 (3), 271–278.

Waddell, J.N.P.A., Swain, M.V., 2006. Physical and metallurgical considerations of failures of soldered bars in bar attachment systems for implant overdentures: a review of the literature. J. Prosthet. Dent. 96 (4), 283–288.

Walton, J.N.M.M., Glick, N., 2002. One-year prosthetic outcomes with implant overdentures: a randomized clinical trial. Int. J. Oral Maxillofac. Implants 17, 391–398.

Watkinson, A.C., 1987. The replacement of attachment-retained prostheses. Quintessence Int. 18, 759–763.

Watson, R.M.J.T., Chai, J., Harnett, J., Heath, M.R., Hutton, J.E., et al, 1997. Prosthodontic treatment, patient response, and the need for maintenance of complete implant-supported overdentures: an appraisal of 5 years of prospective study. Int. J. Prosthodont. 10, 345–354.

Wichmann, M.G.K.W., 1999. Wear behaviour of precision attachments. Int. J. Prosthodont. 12, 409–414.

Wiemeyer, A.S.A.J., Kazemi, R.B., 2001. Orientation of retentive matrices on spherical attachments independent of implant parallelism. J. Prosthet. Dent. 86 (4), 434–437.

Williams, B.H.O.K., Hojo, S., Nishimura, R., Caputo, A.A., 2001. Retention of maxillary implant overdenture bars of different designs. J. Prosthet. Dent. 86 (6), 603–607.

Yang, T.C.M.Y., Gonda, T., Kotecha, S., 2011. Attachment systems for implant overdenture: influence of implant inclination on retentive and lateral forces. Clin. Oral Implants Res. 22 (11), 1315–1319.

You, W.M.R., Romberg, E., Driscoll, C.F., You, T., 2011. The Effect of denture cleansing solutions on the retention of pink Locator Attachments after multiple pulls: an in vitro study. J. Prosthodont. 20 (6), 464–469.