Journal of Oral Rehabilitation 2007 **34**; 41–51

Influence of attachment wear on retention of mandibular overdenture

V. RUTKUNAS*, H. MIZUTANI[†] & H. TAKAHASHI[‡] **Center of Prosthodontics, Institute of Odontology, Faculty of Medicine, Vilnius University, Vilnius, Lithuania, [†]Department of Removable Prosthodontics, and [‡]Department of Advanced Biomaterials, Graduate School, Tokyo Medical and Dental University, Tokyo, Japan*

SUMMARY The aims of this study were: (i) to evaluate and compare retention of two-teeth (implant) supported mandibular overdenture with either stud or magnetic attachments during linear (axial) and rotational (paraxial) dislodgements; (ii) to compare retentive properties before and after wear simulation. The test group consisted of five magnetic and four stud overdenture attachments ($n = 12$ specimens for each attachment type). Retention in axial direction was evaluated on one-tooth (implant) model by measuring maximum retentive force (N) and range of retention (mm) during the linear dislodgement. Retention in the paraxial direction was evaluated on mandibular-overdenture model by measuring the maximum retentive force (N) during three types of rotational dislodgements – anterior, lateral and posterior. The minimum number of cycles required to simulate wear was determined by special wear test. Afterwards, the wear was simulated in the test group, and retention in axial and paraxial directions was measured again. Statistical analysis: one-way ANOVA, Scheffe *post hoc* and paired-samples *t*-tests ($P < 0{\cdot}05$). Initially, studs had higher retention (4–11 N) than magnets (4·5–6 N) in axial direction. After the wear simulation, it had decreased from 76% to 48% for some of the studs and had become similar to the retention of magnetic attachments. Magnets had lower retention range (0·2–0·3 mm) than studs (0·5–1·1 mm). Studs provided similar or higher retention in paraxial directions than magnetic attachments both before and after wear simulation. Retentive properties of magnets decreased mostly with posterior rotational dislodgement. Retentive properties of stud overdenture attachments were less constant.

KEYWORDS: Overdenture, studs, magnetic attachments, retention

Accepted for publication 5 February 2006

Introduction

Tooth- or implant-retained mandibular overdentures have proved themselves to be logical methods to maintain oral function and to delay or eliminate future prosthodontic problems. Preservation of teeth with a healthy periodontium and/or the insertion of implants for edentulous patients are reported to contribute to the preservation of residual ridges, the improvement of masticatory parameters and patient satisfaction (1–4). Because of its simplicity, comparatively low costs, and similar efficiency as that of a fixed implant-supported mandibular prostheses, two-implant-supported mandibular overdentures have been considered by some as the standard of care for edentulous patients (5–7). Many studies have looked into the influence of the overdenture retainer type on retention and stability, burden of maintenance, maximum occlusal force, masticatory function and patient satisfaction (8–13). Studies have compared stud, bar-clip and magnet attachments, which are most commonly employed in retaining tooth-tissue- or implant-tissue-supported mandibular overdentures.

There is no straightforward advice on which type of overdenture attachment is superior. Each of them has their own advantages and shortcomings. Controversy

doi: 10.1111/j.1365-2842.2006.01640.x

exists, either the stud or the bar-clip overdenture attachments require less repairs in post-insertion period (14, 15). However, patient satisfaction tends to be higher with bar-retained overdentures, although some of the studies do not detect any difference (16, 17). Ball and magnetic attachments have been found to induce lower bending moments than bars, simpler to apply and less costly (18–20).

A direct relationship between retention, stability and patient satisfaction has been reported (21–23). Retention is defined as a quality inherent in a prosthesis acting to resist the forces of dislodgement along the path of placement (24).

The majority of studies have evaluated retentive properties of overdenture attachments by only measuring the maximum force in axial direction (25–27). However, in function, overdentures are subjected to three-dimensional displacements in various speeds (28, 29).

Retentive properties of overdenture attachments depend on the type of dislodgement. The ability to retain the overdenture during some of its functional movements varies between different attachments (30). The published data regarding the retention of overdenture during its functional movements are sparse.

The range in which anchoring device is active, i.e. the range of effective retention is an important parameter and has not been clearly documented in research either (31, 32).

Among all implant restorations, the loosening of overdenture retentive mechanisms has been identified as the most common (33%) prosthodontic complication; therefore, routine maintenance is required to ensure successful long-term outcomes (33, 34). Fatigue or failure of overdenture attachments adversely affects their function, maintenance and patient satisfaction (35). After an appropriate number of insertion-removal cycles, attachments obtain more stable retentive properties, which represent the post-insertion period better (36). Accordingly, it is appropriate to compare retentive properties of the attachments in this post-insertion period, and not to limit it to the initial assessment only (37).

Considering the aspects mentioned above, the following aims were selected: (i) to evaluate retentive properties of different stud and magnetic overdenture attachments during linear (axial) and rotational (paraxial) dislodgements, and (ii) to evaluate the effect of wear simulation on them.

The null hypotheses were: there are no differences in retentive properties between the types of overdenture attachments tested, and wear simulation does not influence attachment performance.

Materials and methods

The test group consisted of five commercially available magnetic and four commercially available stud overdenture attachments ($n = 12$ specimens for each attachment type) (Fig. 1 and Table 1). The majority of the attachments tested have identical designs for teeth and implant applications. As high congruence exists between *in vitro* measured retentive properties of overdenture attachments on teeth and implant-imitating models, the results of this study can be applied to both of the treatment concepts – tooth- and implant-supported overdentures (25).

Initially, retentive properties of these attachments were evaluated on a single-tooth (implant) model during linear (axial) dislodgement. Later retentive properties during rotational (paraxial) dislodgement were evaluated on a mandibular-overdenture model. Another test was conducted on new specimens ($n = 3$ specimens for each type of attachment) in order to determine the minimum number of cycles required to achieve relatively constant retentive properties. Afterwards, wear was simulated in the test group, and retention and stability was measured again.

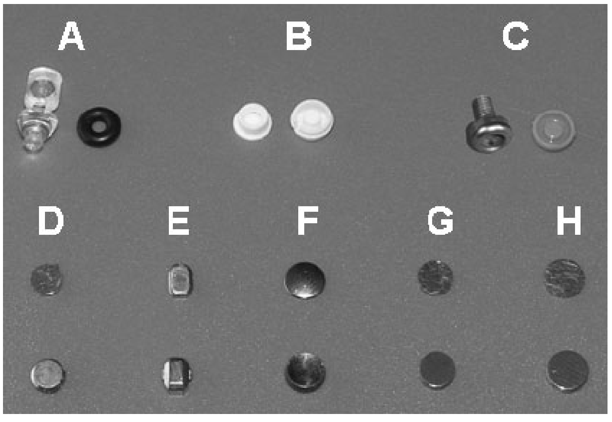

Fig. 1. Types of overdenture attachments tested: (a) OP anchor4, (b) ERA overdenture, (c) Locator root, (d) Magnedisc 500, (e) Magfit EX 600W, (f) Magfit-RK, (g) Hyperslim 4013 and (h) Hyperslim 4513.

Table 1. Magnetic and stud attachments evaluated in study

Attachment	Abbreviations	Material	Height (mm)	Diameter (mm)	Manufacturer
Magnetic attachments					
Magnedisc 500	MD	Magnet – Nd-Fe-B Keeper – AUM 20	1·7	3·5	****
Magfit EX 600W	MF	Magnet – Nd-Fe-B Keeper – AUM 20	2·8	3·8	
Magfit-RK (dome shaped)	RK	Magnet – Nd-Fe-B Keeper – AUM 20 (TiN antiwear coating)	2·3	4·4	
Hyperslim 4013	H40	Magnet – Nd-Fe-B Keeper – XM27	2·1	4	††††
Hyperslim 4513	H45	Magnet – Nd-Fe-B Keeper – XM27	2·1	4·5	
Stud attachments					
OP anchor#4	OP	Male – type IV gold alloy Female – acrylonitrile-butadiene rubber	4·5	5	‡‡‡‡
Locator root (pink)	LRP	Male – DuPont Zytel 101L NC-10 Nylon Female – stainless steel	2	4	§§§§
ERA overdenture (white)	EW	Male – nylon 66 Female – type IV gold alloy	2·9	4·3	¶¶¶¶
ERA overdenture (orange)	EO	Male – nylon 66 Female – type IV gold alloy	2·9	4·3	

****Aichi Steel Co., Aichi, Japan; ††††Hitachi Metals Co., Tokyo, Japan; ‡‡‡‡Inoue Attachments Co., Tokyo, Japan; §§§§Zest Anchors, Escondido, CA, USA; ¶¶¶¶Sterngold, Attleboro, MA, USA.

Specimen preparation

All the attachments, except OP, EO and EW, we prefabricated and did not require casting. Plastic patterns of these attachments were cast from type IV gold alloy*, finished and polished.

Tooth (implant) parts of all the attachments were centred on the heads of non-ferromagnetic screws and glued by epoxy resin†. Denture parts of the attachments were placed on their corresponding parts and embedded into metal rings by auto-polymerizing resin‡, following the instructions of attachment manufacturers (Fig. 2).

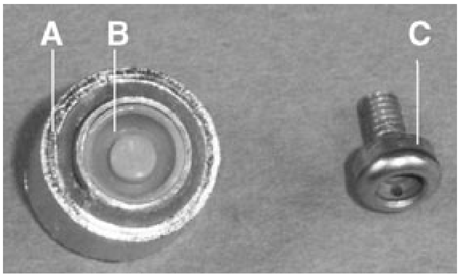

Fig. 2. Specimen preparation: (a) metal ring, (b) denture part of an attachment embedded into metal ring by auto-polymerizing resin, (c) tooth (implant) part of an attachment centred on non-ferromagnetic screw.

Measurements of retention during linear (axial) dislodgement

A one-tooth (implant) model was used to evaluate retention in axial direction. Measurements for this property were performed during linear dislodgement slide perpendicular to the occlusal plane. The abutment model was cast in the shape of canine root from GP Metal alloy§. The central part of it was tapped and was embedded into a block of acrylic resin¶ perpendicular to occlusal plane. The block was attached to the table of universal testing machine**. The tooth (implant) part of the attachment was secured to the abutment model and metal ring containing the den-

*Degulor M; Degussa Dental GmbH & Co., Hanau-Wolfgang, Germany.
†Bond Quick 5; Konichi Co., Osaka, Japan.
‡Unifast Trad; GC, Tokyo, Japan.
§Sankinn Co., Tochigi, Japan.
¶Ostron II; GC, Tokyo, Japan.
**AGS-H; Shimadzu Co., Kyoto, Japan.

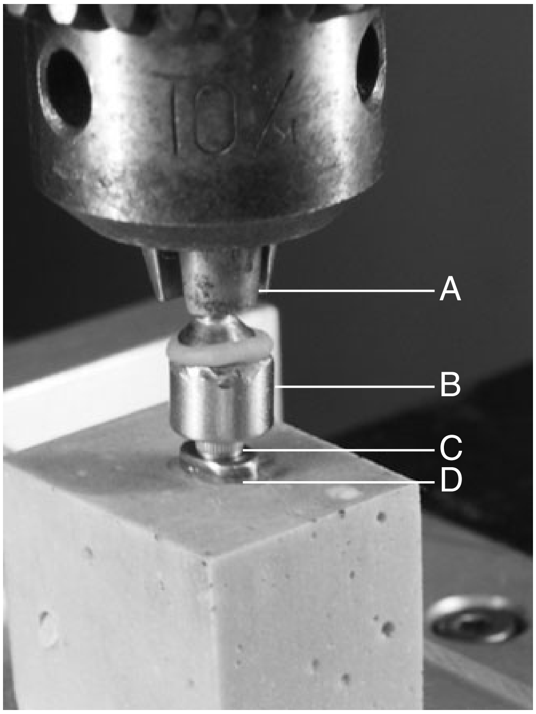

Fig. 3. A one-tooth (implant) model was used to evaluate retention during linear dislodgement: (a) load cell of the testing machine, (b) metal ring containing the denture component of the attachment, (c) non-ferromagnetic screw with tooth (implant) part of attachment, (d) abutment model embedded into a block of acrylic resin perpendicularly to occlusal plane.

ture component of the attachment was seated on it. The denture component was secured to a load cell of the testing machine by means of auto-polymerizing resin‡ (Fig. 3).

For each specimen, 10 dislodgements were performed with cross-head speed of 50 mm min^{-1}, and measurements were recorded by interface software †† with a 50-Hz sampling rate. Two variables were recorded simultaneously during each dislodgement: maximum retentive force (N), and range of retention (mm). The range of retention was measured as separation between attachment components (male and female) in millimetres until retentive force had dropped to 1 N. The testing machine was calibrated before testing each specimen. A period of 10 s between each measurement aided the recovery of the resilient parts of stud attachments.

††Trapezium 1.22; Shimadzu Co.

Measurements of retention during rotational (paraxial) dislodgements

In order to evaluate the resistance of an overdenture to rotational dislodgements, a mandibular model and acrylic metal-reinforced overdenture were fabricated. Two cast abutment models (identical to that used in one-tooth model) were embedded in the region of canines on the mandibular model‡‡ with a distance of 26 mm from their mid-points. The mucosa was simulated using a 3-mm thick silicone layer§§ (38). No undercuts were left on the denture bearing areas. The acrylic¶¶ Cr-Co*** framework-reinforced overdenture-fitting mandibular model was fabricated. Four metal hooks were attached in the regions of both canines and second molars. Twelve specimens in each attachment group were paired randomly into six sets. Tooth (implant) components of the attachments were secured on the abutment models. The denture component of the attachment was seated on its corresponding part and secured to the overdenture base by auto-polymerizing resin‡.

Displacement of overdenture occurs in highly various patterns (39). The mandibular-overdenture model allowed the resistance to certain rotational dislodgements to be evaluated. Three types of rotational dislodgements were investigated: anterior rotational dislodgement, when two chains were attached to the hooks on left and right canines, lateral rotational dislodgement, when two chains were attached to the hooks on the canine and second molar on the left side and posterior rotational dislodgement, when two chains were attached to the hooks on left and right second molars (Fig. 4). Universal testing machine** and interface software†† were used to measure the maximum retentive force (N) under the same conditions as in the retention test.

Simulation of wear

Previous studies have shown that because of the nature of magnetic attraction forces, magnetic attachments show no loss in retention even after 15 000 cycles (25). Therefore, wear was tested and simulated only for the stud attachments. Three new specimens for each type of

‡‡552; Nissin Dental Co. Ltd, Kyoto, Japan.
§§Fit Checker; GC, Tokyo, Japan.
¶¶Acron; GC, Tokyo, Japan.
***Biosil-L; Degussa Dental GmbH & Co.

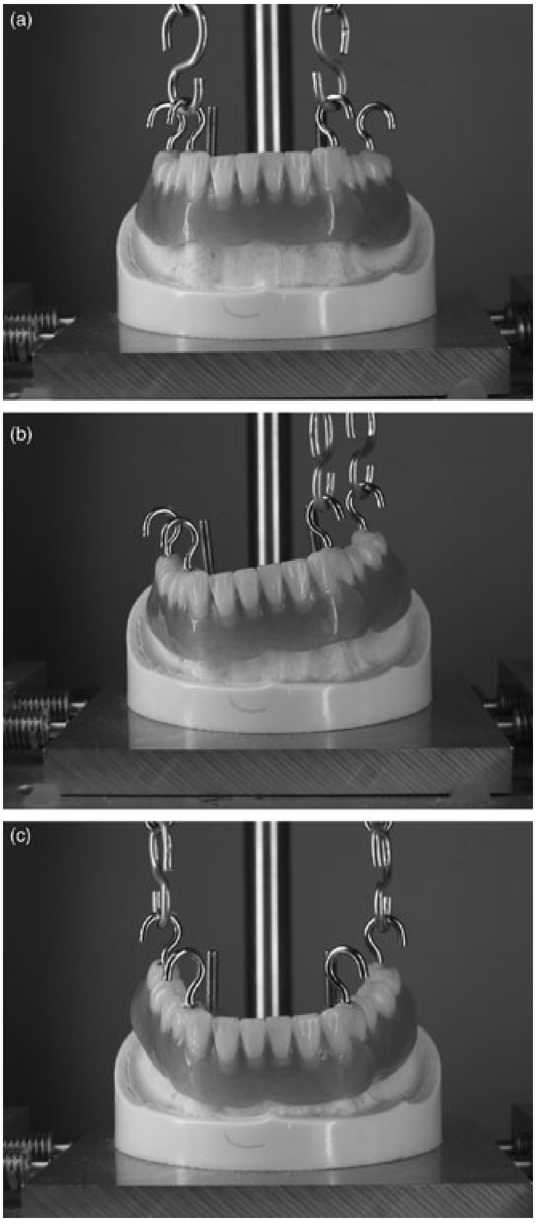

Fig. 4. A mandibular-overdenture model permitted evaluation of retention during three types of rotational dislodgements: (a) anterior, (b) lateral and (c) posterior.

stud attachment were prepared for the fatigue testing. However, as a control, three specimens of magnetic attachments, MF[†††], were also included. A micromaterial testing machine[‡‡‡] with a sensor interface PCD-320 and software package PCD-30A[§§§] were used to test and

[†††]Magfit EX600W; Aichi Steel Co., Aichi, Japan.
[‡‡‡]MMT-250NB-10; Shimadzu Co.
[§§§]Kyowa Electronic Instruments Co., Tokyo, Japan.

Fig. 5. A micromaterial testing machine was used to test and simulate wear.

simulate wear. The tooth (implant) component of the attachment was attached to a jig and the jig was connected to a load cell of fatigue machine. The metal ring containing the denture component of the attachment was seated on its counterpart and secured to the screw fixed at the bottom of the bath by small amount of auto-polymerizing resin[‡]. After the polymerization of the resin occurred, the bath was filled with demineralized water. It was warmed up to 37 °C by 38 °C water circulating outside the bath (Fig. 5). Wear was evaluated under the following conditions: 2000 cycles, 2·5-mm dislodgement, 50 mm min^{-1} dislodgement speed and 100-Hz sampling rate. Initially, and after each 40 cycles, three records of maximum retentive force (N) were recorded and averaged. Mean curves for the wear test are shown in Fig. 6. Wear testing revealed two distinct groups of stud attachments. In the first group, the maximum retentive force increased slightly by the 2000th insertion-removal cycle (OP). In the second group, there was a sudden decrease in retention (LRP, EW and EO). As it was expected, the magnetic

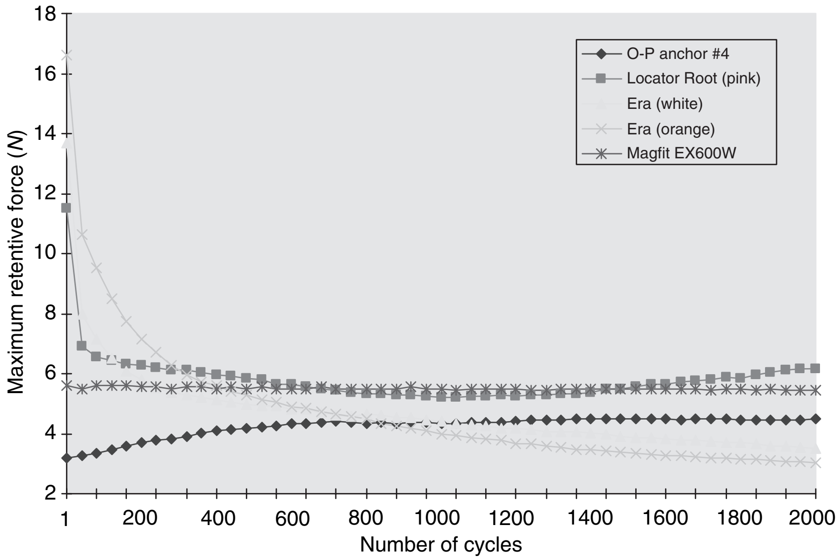

Fig. 6. Average curves representing maximum retentive force (N) changes of OP, LRP, EW, EO and MF during consecutive loading (0–2000 cycles).

attachment tested (MF) preserved constant retention throughout the wear testing period.

According to the number of cycles, all measurements were divided into five groups: 0–400, 400–800, 800–1200, 1200–1600 and 1600–2000. Mean values between each two successive groups were compared for each specimen by a paired-samples *t*-test[¶¶¶]. There was a lower incidence of statistically significant differences between 800–1200 and 1200–1600, 1200–1600 and 1600–2000 groups. Thus, it was assumed that after 800 insertion-removal cycles the stud attachments obtain a relatively stable retention.

In order to simulate wear, all 12 previously tested specimens of each stud attachment were subjected to 800 insertion-removal cycles under the same conditions as for wear testing. Afterwards, the retentive properties during linear and rotational dislodgements were re-evaluated on one-tooth (implant) and mandibular-overdenture models, respectively.

Statistical analysis

Mean values and s.d. were calculated for retentive force and retention range values. Multiple comparisons were made by one-way ANOVA and Scheffe *post hoc* tests with statistical software package[¶¶¶]. Retentive properties before and after wear simulation were compared by paired-samples *t*-test. Statistical significance was set at $P < 0{\cdot}05$.

[¶¶¶]SPSS ver. 11 for Windows; SPSS Inc., Chicago, IL, USA.

Results

ANOVA test revealed significantly ($P < 0{\cdot}05$) different mean values of retentive force and retention range between different types of attachments. Measurements of retentive properties of overdenture attachments, both before and after wear simulation, are presented in Figs 7 and 8. The influence of wear is summarized in Tables 2 and 3.

Retention during linear (axial) dislodgement

Initially, EO had the highest retentive force, followed by LRP, EW, RK, H45, H40, MF, MD and OP. After the simulation of wear, LRP became the most retentive, followed by RK, H45, EW, EO, H40, MF, MD and OP. As a result of fatigue, sudden decrease of retentive force was noticed in EO and EW groups (52% and 46%, respectively). Their retention became lower than that of some of the magnetic attachments. Therefore, after wear simulation, the retentive force of magnets and studs was comparable. Magnets had lower range of retention (0·2–0·3 mm), while that of the studs was significantly higher both before and after wear simulation (0·5–1·1 mm). Retentive force of OP and retention range of LRP increased after wear simulation.

Retention during rotational (paraxial) dislodgements

After wear simulation, LRP provided the highest resistance to anterior rotational dislodgement, followed by H45, EO, EW, H40, RK, MF, MD and OP. According to

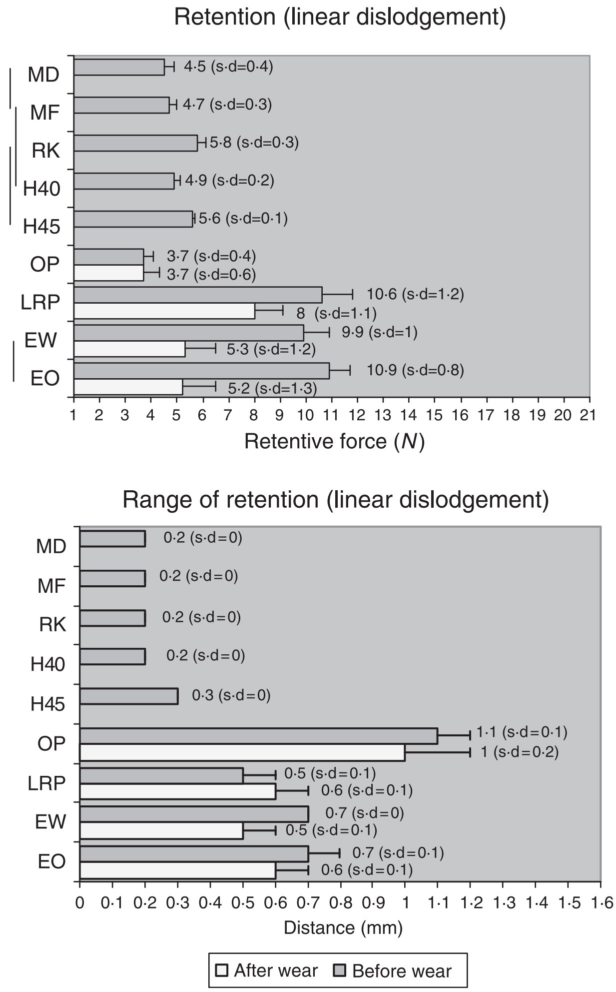

Fig. 7. Retentive properties of stud and magnetic overdenture attachments during linear dislodgement. Bars connect not statistically significant groups after wear simulation ($P < 0{\cdot}05$).

the mean values of force during lateral rotational dislodgement, attachments could be ranked in the following order: LRP, EW, H45, EO, RK, H40, OP, MF and MD, while considering the posterior dislodgement the ranking would be LRP, EO, EW, OP, RK, H45, H40, MF and MD. Retention of overdenture retained by magnetic attachments decreased considerably with posterior rotational dislodgements. After the wear simulation, the retentive properties of EW and EO decreased, while statistically significant increase of retentive force for LRP and OP was noticed during some of the rotational dislodgements. Magnetic attachments provided more constant retentive properties when compared with a relatively high variability in the stud group.

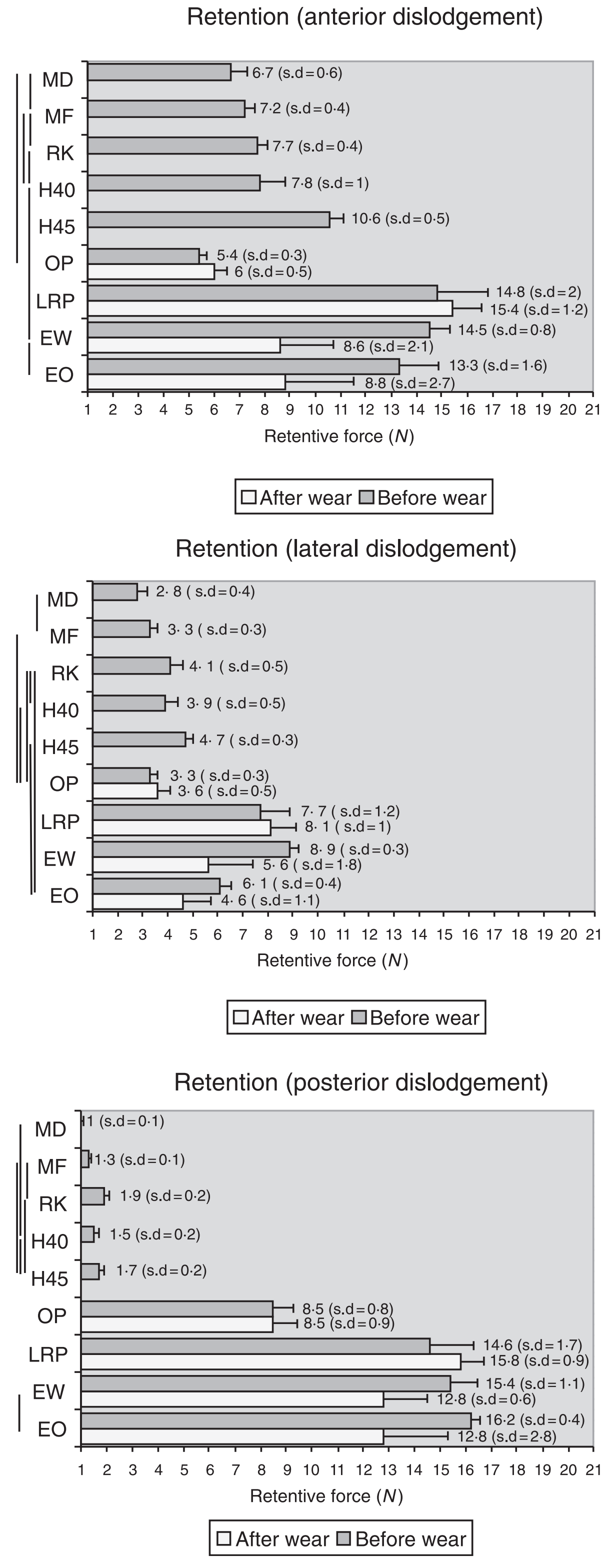

Fig. 8. Retention of stud and magnetic overdenture attachments during rotational dislodgement. Bars connect not statistically significant groups after wear simulation ($P < 0{\cdot}05$).

Table 2. Comparison of retentive properties of overdenture stud attachments before and after wear simulation

Dislodgement	Type	Before wear (N), Mean (s.d.)	After wear (N), Mean (s.d.)	%	*P*
Linear	OP	3·71 (0·43)	3·74 (0·60)	100·81	0·76
	LRP	10·58 (1·24)	8·00 (1·10)	75·61	0·00
	EW	9·89 (0·98)	5·30 (1·15)	53·59	0·00
	EO	10·94 (0·76)	5·24 (1·29)	47·90	0·00
Anterior rotational	OP	5·44 (0·31)	5·95 (0·52)	109·38	0·00
	LRP	14·82 (2·03)	15·36 (1·23)	103·64	0·04
	EW	14·48 (0·81)	8·64 (2·14)	59·67	0·00
	EO	13·25 (1·63)	8·82 (2·66)	66·57	0·00
Lateral rotational	OP	3·26 (0·33)	3·55 (0·48)	108·90	0·00
	LRP	7·65 (1·18)	8·10 (1·00)	105·88	0·04
	EW	8·85 (0·27)	5·58 (1·77)	63·05	0·00
	EO	6·12 (0·38)	4·61 (1·06)	75·33	0·00
Posterior rotational	OP	8·49 (0·78)	8·51 (0·89)	100·24	0·86
	LRP	14·58 (1·69)	15·84 (0·89)	108·64	0·00
	EW	15·37 (1·14)	12·75 (1·66)	82·95	0·00
	EO	16·19 (0·38)	12·81 (2·52)	79·12	0·00

Table 3. Comparison of retention range of overdenture stud attachments before and after wear simulation

Type	Before wear (mm), mean (s.d.)	After wear (mm), mean (s.d.)	%	*P*
OP	1·14 (0·11)	0·99 (0·19)	87·29	0·00
LRP	0·50 (0·06)	0·58 (0·05)	115·57	0·00
EW	0·65 (0·04)	0·54 (0·07)	83·17	0·00
EO	0·73 (0·06)	0·59 (0·07)	81·11	0·00

Discussion

Retention of overdenture was identified as characteristic influencing patient satisfaction (21, 22). Despite the popularity of overdenture stud and magnetic attachments, there is a limited number of studies dealing with their capacity to retain overdenture, as well as of those investigating the influence of wear. The older types of magnetic attachments were reported to be less effective than other types of retainers, less retentive from the perspective of the patient and having high rate of complications, such as corrosion and subsequent demagnetization (11, 40, 41). Clinical experience of more than 10 years with types of magnetic attachments tested in this study does not identify corrosion as their common flaw (42).

Previous studies have measured retentive force of overdenture attachments with a variety of dislodgement speeds ranging from 0·5 mm min^{-1} to 150 mm s^{-1} (43, 44). During a pilot study, the tendency was noticed that higher dislodgement speed results in lower measured value of maximum retentive force. The 50 mm min^{-1} dislodgement speed was selected for the purpose of easier comparison of the results to those of the majority of previous studies.

Nine commercially available overdenture attachments were investigated. Measurements of retention in axial direction before the wear were different from the results reported by other studies, indicating that initially measured retentive forces of same type of attachments vary in wide range (30). All stud attachments except the OP had significantly higher initial retention than the magnetic ones. Similarly, the retention range was from 1·7 to 5·5 times higher in the group of studs. After the wear simulation, the retention of EW and EO decreased (46% and 52% of initial value, respectively) and was in line with the results of a study, which investigated fatigue behaviour of them (45). LRP had lower reduction in maximum retentive force (24% of initial value), thus was less sensitive to wear. The gain in retention noticed for the OP attachment was not statistically significant. A statistically significant decrease of the retention range after wear simulation could be noticed for all studs except LRP.

The retention of overdenture with all types of rotational dislodgements was best ensured with LRP. After the wear simulation, stud and magnetic attachments had comparable retentive parameters during anterior rotational dislodgement. With lateral and posterior rotational dislodgements, the maximum retentive force of magnets decreased considerably – from four to seven times comparing with the anterior rotational dislodgement. During the function, posterior rotational dislodgement of overdenture is one of the most anticipated movements (18), associated with implant (teeth) loading and lower patient satisfaction. Therefore, it is desirable to minimize or eliminate it. Studs ensured the best retention during posterior rotational dislodgement, which was from 4·5 to 15·4 times higher than that of the magnets. This could be one of the possible explanations for the lower satisfaction with magnetic overdentures reported by some studies (16). According to the type of the dislodgement, retentive properties of stud attachments decreased in the following order: posterior > anterior > lateral, whereas with the magnetic ones the order was anterior > lateral > posterior. Considering wear influence on the resistance to the rotational dislodgements, two groups of studs could be distinguished. For the first group (EO and EW), retention decreased. These attachments preserved from 60% to 83% of the retentive force measured before the wear simulation. For the second group, there was an unexpected significant increase in the retentive force of LRP (103–108%) and OP (108–109%) during some of the rotational dislodgements.

It is very complicated to accomplish the measurements of retention and wear intraorally during the function (46). On the other hand, *in vitro* experimental results may not possess adequate clinical relevance. Disagreement between clinical findings and *in vitro* fatigue tests indicates that wear cannot be adequately simulated in *in vitro* studies. Minimal displacement of overdenture in three dimensions during function and parafunction, not well-defined path of insertion of overdenture, implant angulation, as well as the ageing of resilient parts was referred to as possible causes of this disagreement (47, 48).

Wear simulation effects were more evident with types of dislodgements, which occurred in axial direction (vertical linear dislodgement) or close to it (anterior rotational dislodgement). As the direction of dislodgements was farther from axis (lateral and posterior rotational), wear simulation had little, or even opposite, effect on retentive force values. As wear was only simulated in the axial direction, this can be a result of selective wear of certain attachment surfaces (49).

Overall, retentive properties of magnetic attachments were less variable when compared with the studs. It could be hypothesized that retention is easier predictable with this type of attachments. Although loss of retention of magnets was not detected in this study, theoretically their fatigue can appear in other ways (42). However, in a clinical setting, a practitioner should always consider the stress transferred to the abutments and bear in mind that with magnetic attachments it should be easier to prescribe required retention.

Based on empirical findings, some authorities have advocated using retainers, which provide retention of 20 N, and 0·3–0·4-mm retention range for optimum retention of overdenture (25–31). Yet, these recommendations still have not been supported by research.

Conclusions

Within the limits of this study, the following conclusions may be drawn:

1. Retentive properties of overdenture attachments depend on type of dislodgement.
2. Maximum retentive force of magnetic and stud attachments during linear dislodgement slide is comparable.
3. Magnetic attachments have lower retention range.
4. Stud attachments provide significantly better retention of overdenture during posterior rotational dislodgement.
5. Initial retentive properties of stud overdenture attachments are unstable; after 800 insertion-removal cycles, they obtain comparatively low variability.

Acknowledgments

The authors would like to thank Aichi Steel and Hitachi Metals companies for donating attachment specimens, and Dr N. Iwasaki for his invaluable help designing attachment wear experiment.

References

1. Kordatzis K, Wright PS, Meijer HJ. Posterior mandibular residual ridge resorption in patients with conventional dentures and implant overdentures. Int J Oral Maxillofac Implants 2003;18:447–452.
2. Tallgren A. The continuing reduction of the residual alveolar ridges in complete denture wearers: a mixed-longitudinal study covering 25 years. 1972. J Prosthet Dent. 2003;89:427–435.
3. Awad MA, Lund JP, Shapiro SH et al. Oral health status and treatment satisfaction with mandibular implant overdentures and conventional dentures: a randomized clinical trial in a senior population. Int J Prosthodont. 2003;16:390–396.

4. Stellingsma K, Slagter AP, Stegenga B, Raghoebar GM, Meijer HJ. Masticatory function in patients with an extremely resorbed mandible restored with mandibular implant-retained overdentures: comparison of three types of treatment protocols. J Oral Rehabil. 2005;32:403–410.
5. Attard N, Wei X, Laporte A, Zarb GA, Ungar WJ. A cost minimization analysis of implant treatment in mandibular edentulous patients. Int J Prosthodont. 2003;16:271–276.
6. Feine JS, Maskawi K, de Grandmont P, Donohue WB, Tanguay R, Lund JP. Within-subject comparisons of implant-supported mandibular prostheses: evaluation of masticatory function. J Dent Res. 1994;73:1646–1656.
7. Feine JS, Carlsson GE, Awad MA et al. The McGill consensus statement on overdentures. Mandibular two-implant overdentures as first choice standard of care for edentulous patients. Montreal, Quebec, May 24–25, 2002. Int J Oral Maxillofac Implants 2002;17:601–602.
8. Burns DR, Unger JW, Elswick Jr RK, Beck DA. Prospective clinical evaluation of mandibular implant overdentures: Part I – retention, stability, and tissue response. J Prosthet Dent. 1995;73:354–363.
9. van Kampen F, Cune M, van der Bilt A, Bosman F. 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. 2003;14:720–726.
10. van Kampen FM, van der Bilt A, Cune MS, Bosman F. The influence of various attachment types in mandibular implant-retained overdentures on maximum bite force and EMG. J Dent Res. 2002;81:170–173.
11. van Kampen FM, van der Bilt A, Cune MS, Fontijn-Tekamp FA, Bosman F. Masticatory function with implant-supported overdentures. J Dent Res. 2004;83:708–711.
12. Davis DM, Packer ME. Mandibular overdentures stabilized by Astra Tech implants with either ball attachments or magnets: 5-year results. Int J Prosthodont. 1999;12:222–229.
13. Thomason JM, Lund JP, Chehade A, Feine JS. Patient satisfaction with mandibular implant overdentures and conventional dentures 6 months after delivery. Int J Prosthodont. 2003;16:467–473.
14. Walton JN. A randomized clinical trial comparing two mandibular implant overdenture designs: 3-year prosthetic outcomes using a six-field protocol. Int J Prosthodont. 2003;16:255–260.
15. Gotfredsen K, Holm B. Implant-supported mandibular overdentures retained with ball or bar attachments: a randomized prospective 5-year study. Int J Prosthodont. 2000;13:125–130.
16. Cune M, van Kampen F, van der Bilt A, Bosman F. Patient satisfaction and preference with magnet, bar-clip, and ball-socket retained mandibular implant overdentures: a cross-over clinical trial. Int J Prosthodont. 2005;18:99–105.
17. Ambard AJ, Fanchiang JC, Mueninghoff L, Dasanayake AP. Cleansability of and patients' satisfaction with implant-retained overdentures: a retrospective comparison of two attachment methods. J Am Dent Assoc. 2002;133:1237–1242; quiz 1261.
18. Tokuhisa M, Matsushita Y, Koyano K. 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. 2003;16:128–134.
19. Chun HJ, Park DN, Han CH, Heo SJ, Heo MS, Koak JY. Stress distributions in maxillary bone surrounding overdenture implants with different overdenture attachments. J Oral Rehabil. 2005;32:193–205.
20. Thean HP, Khor SK, Loh PL. Viability of magnetic denture retainers: a 3-year case report. Quintessence Int. 2001;32: 517–520.
21. Naert I, Quirynen M, Theuniers G, van Steenberghe D. Prosthetic aspects of osseointegrated fixtures supporting overdentures. A 4-year report. J Prosthet Dent. 1991;65:671–680.
22. Feine JS, de Grandmont P, Boudrias P et al. Within-subject comparisons of implant-supported mandibular prostheses: choice of prosthesis. J Dent Res. 1994;73:1105–1111.
23. Timmerman R, Stoker GT, Wismeijer D, Oosterveld P, Vermeeren JI, van Waas MA. An eight-year follow-up to a randomized clinical trial of participant satisfaction with three types of mandibular implant-retained overdentures. J Dent Res. 2004;83:630–633.
24. Anonymous. The glossary of prosthodontic terms [editorial]. J Prosthet Dent. 1999;81:39–110.
25. Setz I, Lee SH, Engel E. Retention of prefabricated attachments for implant stabilized overdentures in the edentulous mandible: an in vitro study. J Prosthet Dent. 1998;80:323–329.
26. Botega DM, Mesquita MF, Henriques GE, Vaz LG. Retention force and fatigue strength of overdenture attachment systems. J Oral Rehabil. 2004;31:884–889.
27. Svetlize CA, Bodereau Jr EF. Comparative study of retentive anchor systems for overdentures. Quintessence Int. 2004;35:443–448.
28. Mericske-Stern R, Piotti M, Sirtes G. 3-D in vivo force measurements on mandibular implants supporting overdentures. A comparative study. Clin Oral Implants Res. 1996;7:387–396.
29. Akaltan F, Can G. Retentive characteristics of different dental magnetic systems. J Prosthet Dent. 1995;74:422–427.
30. Petropoulos VC, Smith W. Maximum dislodging forces of implant overdenture stud attachments. Int J Oral Maxillofac Implants 2002;17:526–535.
31. Preiskel HW. Fundamentals of mechanical and magnetic attachments. In: Proceedings of the 6th International Symposium on Magnetic Dentistry; 2002 Oct 19–20; Yokohama, Japan: Aichi Steel Co.; 2002:18–19.
32. Petropoulos VC, Smith W, Kousvelari E. Comparison of retention and release periods for implant overdenture attachments. Int J Oral Maxillofac Implants 1997;12: 176–185.
33. Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JY. Clinical complications with implants and implant prostheses. J Prosthet Dent. 2003;90:121–132.
34. Chaffee NR, Felton DA, Cooper LF, Palmqvist U, Smith R. Prosthetic complications in an implant-retained mandibular overdenture population: initial analysis of a prospective study. J Prosthet Dent. 2002;87:40–44.
35. Payne AG, Solomons YF. Mandibular implant-supported overdentures: a prospective evaluation of the burden of

prosthodontic maintenance with 3 different attachment systems. Int J Prosthodont. 2000;13:246–253.
36. Besimo CE, Guarneri A. In vitro retention force changes of prefabricated attachments for overdentures. J Oral Rehabil. 2003;30:671–678.
37. Chung KH, Chung CY, Cagna DR, Cronin Jr RJ. Retention characteristics of attachment systems for implant overdentures. J Prosthodont. 2004;13:221–226.
38. Mizuuchi W, Yatabe M, Sato M, Nishiyama A, Ohyama T. The effects of loading locations and direct retainers on the movements of the abutment tooth and denture base of removable partial dentures. J Med Dent Sci. 2002;49:11–18.
39. Federick DR, Caputo AA. Effects of overdenture retention designs and implant orientations on load transfer characteristics. J Prosthet Dent. 1996;76:624–632.
40. Naert I, Alsaadi G, Quirynen M. Prosthetic aspects and patient satisfaction with two-implant-retained mandibular overdentures: a 10-year randomized clinical study. Int J Prosthodont. 2004;17:401–410.
41. Riley MA, Williams AJ, Speight JD, Walmsley AD, Harris IR. Investigations into the failure of dental magnets. Int J Prosthodont. 1999;12:249–254.
42. Mizutani H, Rutkunas V. Maintenance of magnetically retained overdentures and troubleshooting. In: Ai M, Shiau Y, eds. New Magnetic Applications in Clinical Dentistry. Tokyo: Quintessence; 2004:97–109.
43. Williams BH, Ochiai KT, Hojo S, Nishimura R, Caputo AA. Retention of maxillary implant overdenture bars of different designs. J Prosthet Dent. 2001;86:603–607.
44. Walton JN, Ruse ND. In vitro changes in clips and bars used to retain implant overdentures. J Prosthet Dent. 1995;74:482–486.
45. Gamborena JI, Hazelton LR, NaBadalung D, Brudvik J. Retention of ERA direct overdenture attachments before and after fatigue loading. Int J Prosthodont. 1997;10:123–130.
46. Setz JM, Wright PS, Ferman AM. Effects of attachment type on the mobility of implant-stabilized overdentures – an in vitro study. Int J Prosthodont. 2000;13:494–499.
47. Breeding LC, Dixon DL, Schmitt S. The effect of simulated function on the retention of bar-clip retained removable prostheses. J Prosthet Dent. 1996;75:570–573.
48. Walton JN, Huizinga SC, Peck CC. Implant angulation: a measurement technique, implant overdenture maintenance, and the influence of surgical experience. Int J Prosthodont. 2001;14:523–530.
49. Wichmann MG, Kuntze W. Wear behavior of precision attachments. Int J Prosthodont. 1999;12:409–414.

Correspondence: Vygandas Rutkunas, Center of Prosthodontics, Institute of Odontology, Faculty of Medicine, # 231, Zalgirio Street 115, Vilnius University, 08217 Vilnius, Lithuania.
E-mail: vygandasr@gmail.com