ACP
AMERICAN COLLEGE OF PROSTHODONTISTS®

Mechanical Properties of Magnetic Attachments for Removable Prostheses on Teeth and Implants

Arne F. Boeckler, DMD,[1] Dean Morton, BDS, MS,[2] Carolin Ehring, DMD,[1] & Juergen M. Setz, DMD, PhD[1]

[1] Centre for Dentistry and Oral Medicine, Department of Prosthodontics, Martin Luther University, Halle-Wittenberg, Germany
[2] Center for Implant Dentistry, University of Florida, Gainsville, FL

Keywords
Retention; retentive force; keeper; overdenture.

Correspondence
Arne F. Boeckler, Martin Luther University Halle-Wittenberg, Centre for Dentistry and Oral Medicine, Department of Prosthodontics, Grosse Steinstr. 19, Halle (Saale) 06108, Germany. E-mail: arne.boeckler@medizin.uni-halle.de

Presented at the International Association of Dental Research (IADR), 83rd General Session & Exhibition, March 9-12, 2005, Baltimore, MD.

Accepted September 20, 2007

doi: 10.1111/j.1532-849X.2008.00356.x

Abstract

Purpose: Magnetic attachments on teeth and implants may be used to improve stability, support, and retention of removable prostheses. Various forms of magnetic attachments are available, divided according to the design, the mechanical properties of the attachments, and the clinical indication. Recently developed attachment systems are small and promise improved retentive capacity, while existing magnetic attachments continue to be technologically modified and improved. This investigation reviewed and compared maximum retentive forces and characteristic curves for magnetic attachments indicated for use as root anchors and on implants.
Materials and Methods: Twenty-four samarium-cobalt (SmCo) and neodym-iron-boron (NeFeB) magnetic attachments (12 tooth- and 12 implant-borne) were evaluated. Specimens were delivered by the manufacturers or fabricated according to their instructions. Five magnet pairs of each product and each combination were tested 10 times in a calibrated universal testing machine using a nonmagnetic test device ($s = 40$ mm, $v = 20$ mm/min). Results were recorded electronically and compared to manufacturers' details.
Results: Maximum retentive forces for root keepers ranged from 1.4 to 6.6 N. Maximum retentive forces for magnetic attachments on implants ranged from 0.7 to 5.8 N. After a distance of 0.1 mm, a complete reversed distribution of the different systems became obvious. The retentive force provided by the manufacturer was achieved in one implant abutment, with retentive force (as compared to those provided by the manufacturers) for root keepers ranging between 42.5% and 92.9% and for implant abutments between 43.0% and 99.4%.
Conclusion: There were differences between magnetic attachments for both the initial retentive capabilities and the characteristic curves. Recently introduced products provided relatively high initial retentive forces despite their small size. The measured retentive forces and the manufacturer's information differed in the majority of magnetic systems evaluated.

Magnets have been used in various fields of dentistry for about 60 years. As magnets are readily available and simple to use,[1] they have often been used and evaluated in the stabilization and retention of removable dental prostheses. Initially the repulsion power of large volume aluminum-nickel-cobalt (AlNiCo) magnets was integrated into complete dentures for patients with highly atrophied alveolar ridges.[1] Soon after, the attractive forces between magnets were successfully used to increase retention of mandibular complete dentures, with magnets of differing alloys being implanted in edentulous jaws.[2] These initial efforts were associated with a range of complications, including low magnetic forces, large implant size, corrosion, expense, and procedural difficulties, and were therefore only marginally successful.[1]

The development of samarium-cobalt (SmCo) magnets and, later, neodym-iron-boron (NdFeB) magnets[3] resulted in essential improvements. These magnets were smaller and yet produced more usable retentive forces. Consequently, the use of remaining teeth to support magnets to retain and stabilize removable dental prostheses became more realistic.[4] Concerns regarding tissue health and the biocompatibility of cemented permanent magnets led to the development of keepers. Keepers

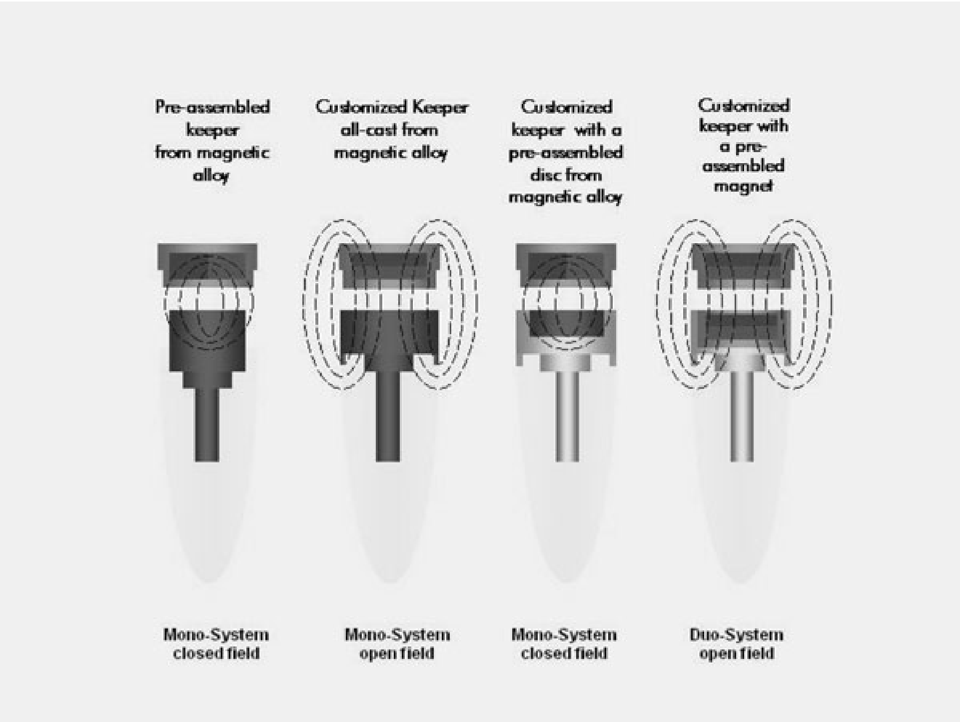

Figure 1 Classification of magnetic attachments on preserved dental roots.

are individually cast post and root cap components of an attachment system incorporating industrially produced magnetizable discs, or are available in prefabricated forms.[5,6] Keepers do not possess a permanent magnetic field; rather, they are made of magnetizable alloys.[1] The diameter of the corresponding magnet in the prosthesis is determined by the size of the disc in the keeper.[7]

For conventional removable dental prostheses, magnetic attachments can be used to improve retention.[8,9] The use of magnetic attachments in conjunction with endosseous implants has also been described.[10,11] Initially restricted to maxillofacial indications, including craniofacial deficiencies and epithetics,[12-14] the use of magnetic attachments has been successfully established for implant-retained removable dental prostheses. Clinical and in vitro studies confirmed the advantages of magnetic attachments for these indications[11,15-22] Advantages include control of load transmitted to implants, and the relative ease of prosthesis fabrication in complicated patients.

A variety of magnetic systems are available. These can be divided into open and closed magnetic systems[1] (Figs 1 and 2). For open systems, a static magnetic field exists around the two magnetic components in close contact with each other. Food particles or permanent deposits (including debris and calculus) may result in the separation of corresponding magnetic

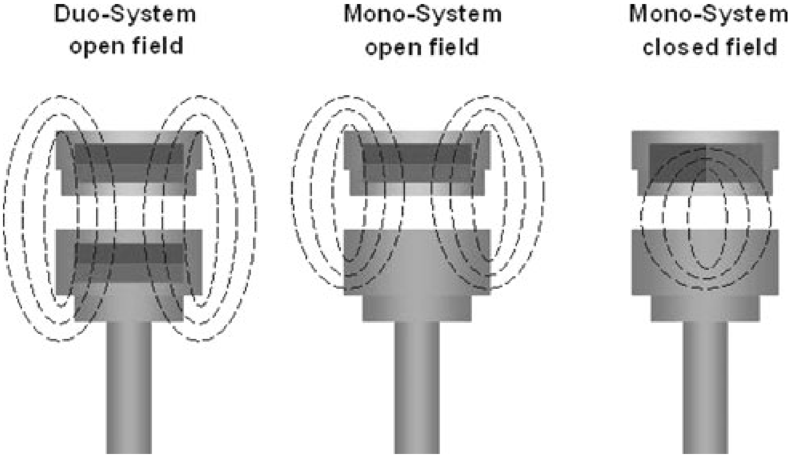

Figure 2 Classification of magnetic attachments on dental implants.

pairs.[23] When the magnets are separated, the magnetic force of attraction decreases nonlinearly. This effect is less dramatic in an open magnetic field. Furthermore, a self-centering of the prosthesis is possible.

Depending on the design, the magnetic field in closed systems is within the magnetic components in contact with each other (Figs 1 and 2).[24] Thus, in contrast to an open system, the magnetic field in the oral cavity is reduced significantly.[1] Compared to an open system of the same size, the effectiveness of the magnetic anchorage rises. But if the corresponding magnets are separated, the retention force will decline more rapidly than observable for an open system of the same size.[25,26] In addition, there is a difference between mono and duo systems (Figs 1 and 2). For mono systems, the magnetic pair incorporates a soft alloy with no static magnetic field, but which can easily be magnetized.[1] This system saves space, and may be applied as a keeper on preserved roots or as a manufactured abutment on implants. A duo system consists of two polarized magnets, one of which acts as a keeper or abutment being permanently positioned in the mouth. In contrast to mono systems, the components can be completely housed in titanium.[1] Recent research has shown no negative effects of such magnetic fields on soft tissue.[1,27]

Recently developed magnetic retention systems are very small. According to details given by manufacturers, the retentive forces are very high. Established and reliable magnetic attachments continue to be technologically modified and improved.[28] On the basis of these technical improvements and simple and economical clinical use[21] as compared to precision attachments, there may be a wider indication for the use of magnetic attachments in removable prosthodontics in addition to implant prosthodontics. These advantages may be especially applicable to older or handicapped patients.[29]

Retentive force is an important consideration in the selection of attachments.[15,18] Data on sufficient retention force has fluctuated between 0.2[30] and 19.9 N.[31] To provide sufficient retention without damaging the surrounding tissues, forces between 4 and 10 N seem to be desirable.[32] Magnetic attachments are classified according to the differences between their initial maximum retentive force and their characteristic curves, which relate to the increasing distance between the poles. Using various test arrangements, several authors have evaluated this.[12,24,28,33–36] It has been shown that the measured retentive forces are often below those provided by the manufacturers;[7] however, in contrast to precision attachments, retentive forces are not reduced by cycled pull-off forces.[7,10,37]

This investigation aimed at a standardized revision and comparison of the maximum pull-off forces and characteristic curves of magnetic attachments for use on preserved roots and on dental implants.

Materials and methods

Twelve magnetic attachments for use on preserved roots (Table 1) and 12 magnetic attachments for dental implants were tested (Table 2).

In the case of magnetic attachments for root-(posted)-caps, different combinations of prosthesis magnets as well as keepers recommended by the manufacturers were tested (Table 1). Tests of one open-duo-system (ODS) and of seven closed- (CMS) and four open-mono-systems (OMS) were performed. As far as magnetic alloys were concerned, SmCo played a role in only one case, NeFeB in all others.

For the magnetic attachments on implants, four ODS, two OMS, and six CMSs were investigated. The magnetic alloy was SmCo in three systems and NeFeB in all others. Magnetic abutments for implants are provided for different implant systems in unlike designs by the respective manufacturers. Therefore, to create a standard, all abutments were tested for the same implant system (Straumann Implant System, Waldenburg, Switzerland).

According to manufacturers' instructions, discs with a relevant diameter of the prosthesis magnet were cast of ferromagnetic alloys to produce customized root caps. Tests proved that the thickness of the ferromagnetic keeper above 1 mm does not exert any influence on the retention force. Additionally, the

Table 1 Tested magnetic attachment systems on teeth

Manufacturer	Product		Magnet system	Magnetic field	Magnetic alloy	Total height (mm)	Diameter (mm)
	Keeper/Insert	Prosthesis magnet					
Aichi, Tokyo, Japan	Magfit DX 400	Magfit DX 400	Mono	Closed	NeFeB	1.5	3
	Magfit DX 600	Magfit DX 600	Mono	Closed	NeFeB	1.9	3.6
	Magfit DX 800	Magfit DX 800	Mono	Closed	NeFeB	2.1	4
Dyna, Bergen op Zoom, The Netherlands	Direct-System-Keeper	WR-Magnet S3 small	Mono	Open	NeFeB	3	4.2
	Direct-System-Keeper	WR-Magnet S5 standard	Mono	Open	NeFeB	4	4.27
	EFM Alloy	WR-Magnet S3 small	Mono	Open	NeFeB	2.7	5
	EFM Alloy	WR-Magnet S5 standard	Mono	Open	NeFeB	3.7	5
Steco, Hamburg Germany	Titanmagnetics root cap system	Titanmagnetics root cap system	Duo	Open	SmCo	5.15	4.8
Technovent, Leeds, UK	Mini Insert Keeper	Mini Magnacap	Mono	Closed	NeFeB	4	4.5
	Maxi Insert Keeper	Maxi Magnacap	Mono	Closed	NeFeB	4.7	5.5
	Mini Post Keeper	Mini Magnacap	Mono	Closed	NeFeB	4.3	4.5
	Maxi Post Keeper	Maxi Magnacap	Mono	Closed	NeFeB	5	5.5

Table 2 Tested magnetic attachment systems on endosseous implants

Manufacturer	Product: Implant abutment	Product: Prosthesis magnet	Magnet system	Magnetic field	Magnetic alloy	Total height (mm)	Diameter (mm)
Aichi	Magfit-IP-IDN abutment keeper	Magfit-IP-IDN dome type	Mono	Closed	NeFeB	2.9	4.5
	Magfit-IP-IFN abutment keeper	Magfit-IP-IFN flat type	Mono	Closed	NeFeB	2.8	4.4
Brasseler	Komet MicroPlant Primary anchor	Komet MicroPlant Secondary anchor	Duo	Open	NeFeB	6.7	4.4
Dyna	Medical-Abutment	WR-Magnet S3 small	Mono	Open	NeFeB	4.7	4.2
	Medical-Abutment	WR-Magnet S5 standard	Mono	Open	NeFeB	5.7	4.27
Steco	X-Line Titanmagnetics Insert	X-Line Titanmagnetics	Duo	Open	SmCo	6.65	4.8
	Z-Line Titanmagnetics Insert	Z-Line Titanmagnetics	Duo	Open	SmCo	8.15	5.8
	K-Line Titanmagnetics Insert	K-Line Titanmagnetics	Duo	Open	SmCo	10.5	5.2
Technovent	Mini Magnabutment	Micro Magnacap	Mono	Closed	NeFeB	4.5	4.5
	Mini Magnabutment	Mini Magnacap	Mono	Closed	NeFeB	5.3	4.5
	Maxi Magnabutment	Midi Magnacap	Mono	Closed	NeFeB	5.3	5.5
	Maxi Magnabutment	Maxi Magnacap	Mono	Closed	NeFeB	6	5.5

length of a post or the size of a possible inlay do not have any influence.[35] Compared to the corresponding denture magnet, only a small lateral overextension of these discs makes sense.[7] The discs of 1-mm thickness were then thoroughly smoothed out and highly polished.[35]

There were five pairs (implant abutment and prosthesis magnet, respectively, and keeper and prosthesis magnet) of each product and each combination tested in a calibrated universal test machine (Z005, Zwick, Ulm, Germany) using a custom-made nonmagnetic test device (Fig 3).[35] Therefore, one part of the device was fixed to the base plate. There were two versions of this device. One carried the keeper, which was fixed by a small amount of glue. The other version was constructed with an implant lab analog to hold the implant abutment keeper. The corresponding part of the testing device was connected to the measuring traverse with a nonstretchable and nonmagnetic wire. The denture magnet was fixed on its backside by a small amount of glue. Measurements were performed at a crosshead speed of 20 mm/min. Preliminary tests showed that after 2 mm for most of the products, no retentive force could be proved. So the crosshead moved 40 mm perpendicular to the base plate and axial to the keeper or implant.

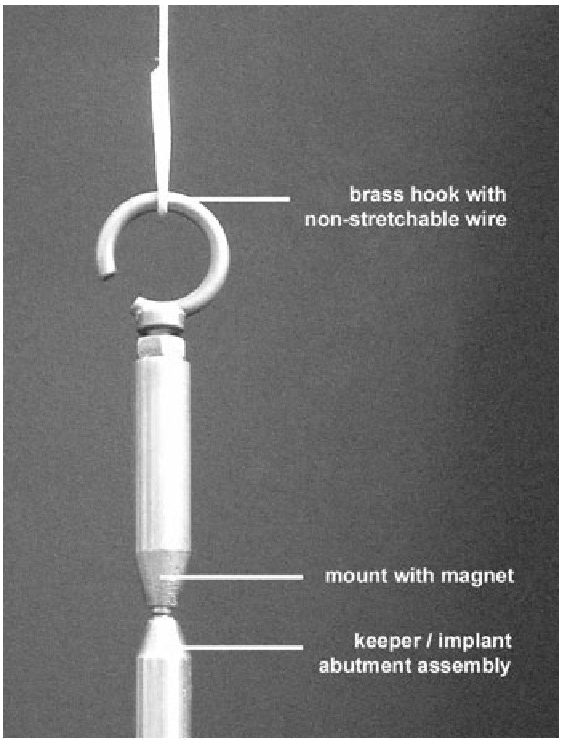

Figure 3 Nonmagnetic testing device connected to the measuring traverse with a nonstretchable wire.

Measurings were repeated 10 times for each magnetic pair (two components), and the mean was taken as the result for the tested magnet pair. Results were recorded electronically. The mean and the 95% confidence interval of the five magnet pairs of each product were calculated, statistically tested (SPSS 10.0, SPSS, Inc., Chicago, IL), and compared to the manufacturers' details (t-test, $p < 0.05$).

Results

For root keepers, the highest pulling-off force was 6.6 N. The lowest pulling-off force was 1.4 N (Table 3, Fig 4). The highest retentive forces were found within the CMSs. A distance of the corresponding magnetic components of 0.1 mm resulted in a reversed distribution of the measured forces. While the retentive force of the ODS reduced to 89%, the retention forces of the OMS reduced to approximately 75%, in contrast to CMS with only 0.6 to 20% of their initial force. As the size of those pulling-off forces depends on the respective measurements of the single magnet type, percentage deviations of retentive forces were fixed by respective manufacturers' details. Correspondence could not be found in any of the tested products. For two products, the results were over 90% and for five products, over 70% (but less than 90%). For four products, the

Table 3 Results for the tested magnetic attachment systems for teeth

Manufacturer	Product	n	Retentive force according to manufacturers' information (N)	Measured maximum retentive force (mean) (N)	95 % Confidence interval Minimum level (N)	Maximum level (N)	Percentage between measured mean force and manufacturers' information (%)	Significance $p < 0.05$
Aichi	Magfit DX 400	5	3.90	2.48	2.09	2.87	63.5	0.001
	Magfit DX 600	5	5.90	4.15	3.59	4.71	70.3	0.001
	Magfit DX 800	5	7.90	6.16	5.40	6.92	78.0	0.003
Dyna	WR-Magnet S3 EFM Alloy	5	2.90	1.37	1.27	1.47	47.2	0.000
	WR-Magnet S5 EFM Alloy	5	4.90	2.08	1.96	2.21	42.5	0.000
	WR-Magnet S3 Direct Keeper System	5	2.90	1.44	1.32	1.57	49.8	0.000
	WR-Magnet S5 Direct Keeper System	5	4.90	2.11	1.98	2.24	43.1	0.000
Steco	Steco magnetic root cap system	5	1.70	1.58	1.52	1.64	92.9	0.004
	Mini Magnacap Mini Insert Keeper	5	4.00	2.80	2.47	3.13	70.0	0.001
Technovent	Maxi Magnacap Maxi Insert Keeper	5	7.20	5.66	5.17	6.15	78.6	0.001
	Mini Magnacap Mini Post Keeper	5	4.00	3.05	2.57	3.53	76.3	0.005
	Maxi Magnacap Maxi Post Keeper	5	7.20	6.57	6.11	7.03	91.2	0,019

measured forces were less than 50% below the manufacturers' details.

For magnetic attachments on implants, the highest initial retentive force was 5.8 N. The lowest retentive force was 0.7 N (Table 4, Fig 5). The characteristic curves showed differences among the single products. In addition to the specific results for the retentive forces, characteristic curves occurred depending on the

Table 4 Results for the tested magnetic attachment systems for implants

Manufacturer	Product	n	Retentive force according to manufacturers' information (N)	Measured maximum retentive force (mean) (N)	95 %Confidence interval Minimum level (N)	Maximum level (N)	Percentage between measured mean force and manufacturers' information (%)	Significance $p < 0.05$
Aichi	Magfit-IP BDN/IDN	5	5.90	4.77	4.13	5.40	80.78	0.008
	Magfit-IP BFN/IFN	5	6.40	5.34	4.80	5.87	83.38	0.005
Brasseler	Komet Micro Plant	5	1.50	0.67	0.61	5.40	44.53	0.000
Dyna	WR-Magnet S3	5	2.90	1.45	1.32	1.58	49.93	0.000
	WR-Magnet S5	5	4.90	2.11	2.02	2.27	42.98	0.000
Steco	K-Line	5	1.60	1.49	1.45	1.54	93.38	0.002
	X-Line	5	1.70	1.58	1.52	1.64	92.94	0.004
	Z-Line	5	3.00	2.98	2.89	3.07	99.40	0,612
Technovent	Micro Magnacap Mini Magnabutment	5	3.00	2.61	5.08	6.44	86.93	0.008
	Mini Magnacap Mini Magnabutment	5	4.00	3.08	2.14	3.08	77.00	0.024
	Midi Magnacap Maxi Magnabutment	5	6.20	4.97	4.31	5.64	80.19	0.007
	Maxi Magnacap Maxi Magnabutment	5	7.20	5.76	2.37	3.80	80.00	0.004

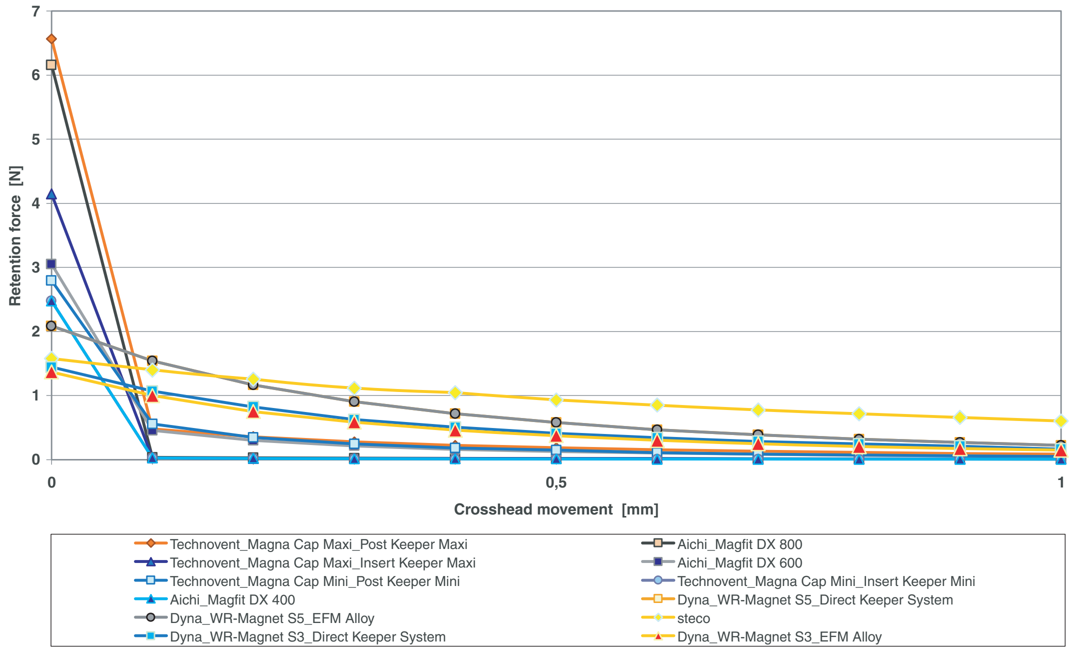

Figure 4 Characteristic curves of the tested magnetic attachment systems for teeth.

tested systems. The strongest retentive forces were found in CMS and the lowest in ODS. For a magnetic distance of 0.1 mm, a completely reversed distribution became obvious. While the retentive forces in ODS were reduced to 89%, CMS reached 0.4 to 16% of their initial forces. The reductions in the OMS were intermediate. As the amount of retentive force depends on the respective measurement of the individual magnet type, deviations of the measured initial retentive forces and the respective manufacturers' details were found. In one product, no significant difference between measured retentive force and manufacturers' details could be found. For two other products, the retention was more than 90% and for six products more than 75% (but less than 90%). For three products the measured forces were less than 50% below the manufacturers' details.

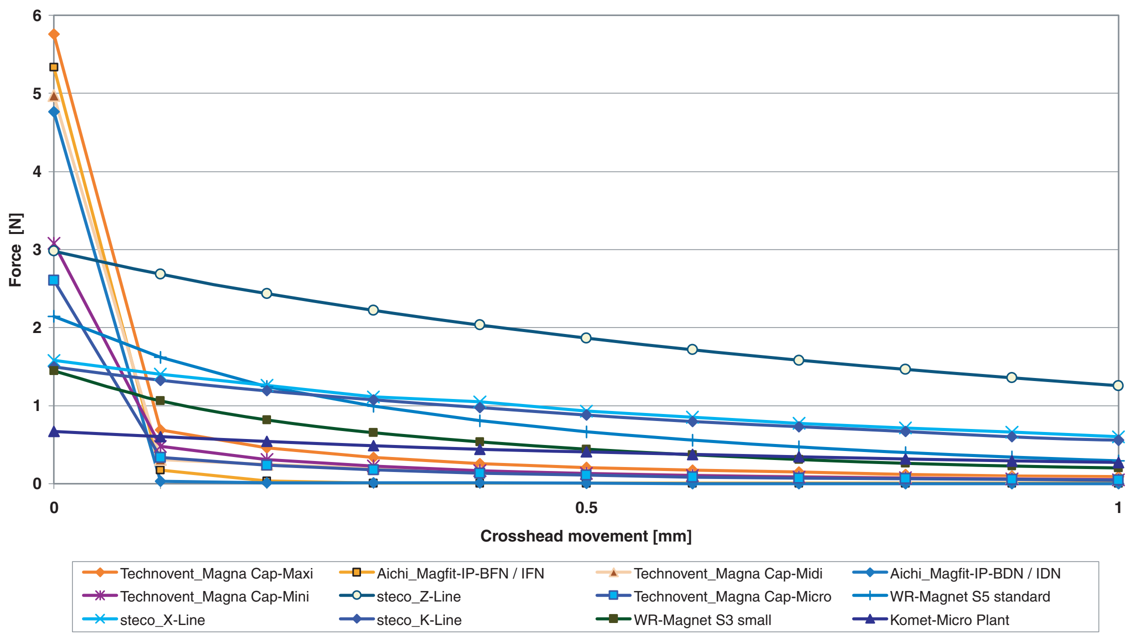

Figure 5 Characteristic curves of the tested magnetic attachment systems for implants.

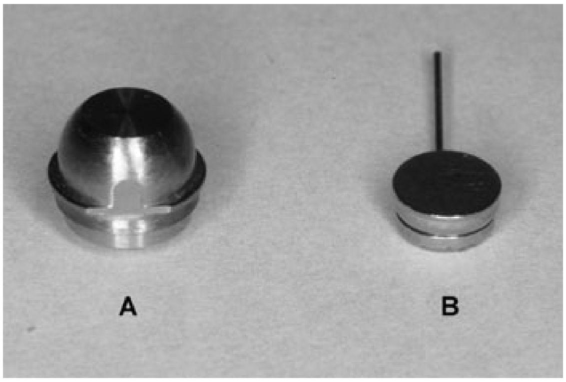

Figure 6 Magnetic attachments for roots: comparison of the overall height of the two systems with the highest retentive force—(A) Maxi Magnacap + Maxi Post Keeper, h = 5 mm; (B) Magfit DX 800, h = 2.1 mm.

Discussion

The maximum retentive force of a magnetic attachment is the force required to cause initial separation of the magnet from its opposing attractive element, which in the present study were root keepers or magnetic implant abutments. Besides other parameters, the breakaway force of magnetic attachments depends on the speed of separation of the two components.[12,25] As there are no generally valid instructions available for fixing the characteristic curves of magnetic attachments (e.g., ISO norms), measuring was made in accordance with previous studies in a calibrated universal test machine, using a custom-made, nonmagnetic test device at a crosshead speed of 20 mm/min and a movement of 40 mm.[7,12,28]

The results of measuring both implant abutments as well as keepers proved differences exist between the different systems. The characteristic curves of OMS, CMS, and ODS were typical for the respective underlying physical effect principles[1,25,34] and the tested magnetic alloys.[3]

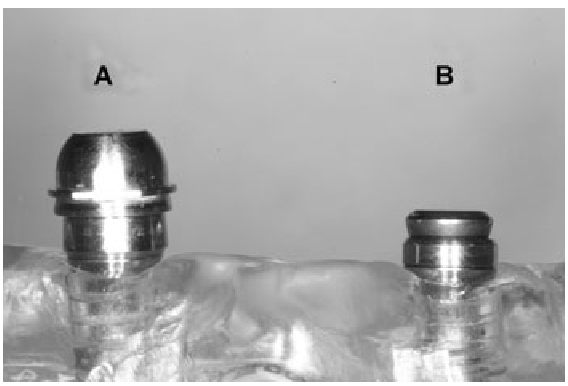

Figure 7 Magnetic attachments for implants: comparison of the overall height of the two systems with the highest retentive force—(A) - Maxi Magnacap + Maxi Abutment, h = 6 mm; (B) Magfit-IP BFN/IFN, h = 2.8 mm.

The strongest initial retentive forces in keepers and in abutments were reached by a CMS with a NeFeB magnet (6.6 and 5.8 N, respectively). A recently developed magnetic attachment for root caps related to its small construction height of 2.1 mm reached the second highest retention results of 6.2 N among the keepers, where the highest retention of 6.6 N was observed in an attachment with a height of 5 mm (Fig 6). A comparable small implant abutment (total height 2.8 mm) distributed by the same manufacturer showed the second highest retention results (5.3 N) among the implant abutments, where the highest retention (5.8 N) was found in a magnetic attachment system with a height of 6 mm (Fig 7); however, with an increasing gap width, the initial retentive force significantly decreased in these products. With an only 1.1-mm thick root keeper (diameter 5.4 mm), higher results were reached than with a 2.1-mm high implant abutment (diameter 5.1 mm). This result corresponds with the results of Darvel and Dias[7] as well as Wisser et al,[35] where for retentive force, the diameter seems to be more important than height.

ODS with SmCo or NeFeB magnets had lower initial forces; however, no abrupt diminishing of the retention effect could be observed with an increasing magnet distance. Thus, they provide better conditions for a safe self-centering of the prosthesis. The results and characteristic curves of OMS on NeFeB were between the groups mentioned above.

With the exception of one product, in this study all the magnetic attachments produced significantly less retention than the number provided by the respective manufacturer. This corresponds with the results by Wisser et al.[35] The authors assume that some manufacturers gave the retentive force of the magnetic alloys without consideration of the thickness of the individual housing of the magnet. Technically there is a primary distance between abutment or keeper and the rare earth prosthesis magnet. As the maximum retentive force could also depend on the respective pulling-off crosshead speed, a further reason for this deviation in different speeds of the tested specimen might be found when measuring.[12,25] For this reason, Wisser et al[35] recommended standardized tests and characteristic curves for objective assessments of technical features of magnetic attachments on the part of manufacturers.

When assessing the measured retentive forces, none of the attachments tested reached the retentive force given by Bates;[31] however, all attachments initially exceeded the 0.2 N given by Hargraves and Foster.[30] If the retentive forces of 4 to 10 N recommended by Lehmann and Arnim[32] are taken as a basis, necessary minimum results were measured for 33% of magnetic attachments on implants and 42% of magnetic attachments on teeth. As these are the maximum values under in vitro conditions, the decision as to the specific magnetic system, as well as to the number of magnets required for the retention of a denture or a complete overdenture must be made with care.

Conclusion

There were differences between magnetic systems for both the initial retentive forces as well as the clinically important characteristic curves for magnetic attachments on preserved roots and implants. Recently introduced products, regardless of their small construction size, provide considerably high retentive forces. Therefore, such systems may become a viable alternative, particularly in patients with a limited vertical space. In comparing the measured retentive forces and the manufacturer's information, differences were noted for the majority of the systems tested. In accordance with the individual conditions in the oral cavity, these results may be taken into consideration for the individual choice of magnetic attachments.

References

1. Riley M, Walmsley A, Harris I: Magnets in prosthetic dentistry. J Prosth Dent 2001;86:137-142
2. Behrman S: The implantation of magnets in the jaw to aid denture retention. J Prosthet Dent 1960;10:841
3. Sagawa S, Furimura S, Togowa N, et al: New material for permanent magnets on base of Nd and Fe. J Appl Phys 1984;55:2083-2087
4. Moghadam B, Scandrett F: Magnetic retention for overdentures. J Prosthet Dent 1979;41:26-29
5. Smith G, Laird W, Grant A: Magnetic retention units for overdentures. J Oral Rehabil 1983;10:481-488
6. Wang N, von der Lehr W: The direct and indirect techniques of making magnetically retained overdentures. J Prosth Dent 1991;65:112-117
7. Darvell BW, Dias AP: Non-inverse-square force-distance law for long thin magnets. Dent Mater 2006;22:909-918
8. Gillings B: Magnetic retention for overdentures. Part II. J Prosthet Dent 1983;49:607-618
9. Jonkman R, VanWaas M, Kalk W: Satisfaction with complete intermediate dentures and complete intermediate overdentures. A 1-year study. J Oral Rehabil 1995;22:791-796
10. Jackson T: The application of rare earth magnetic retention to osseointegrated implants. Int J Oral Maxillofac Implants 1986;1:81-92
11. Carlyle L, Duncan J, Richardson J, et al: Magnetically retained implant denture. J Prosthet Dent 1986;56:583-586
12. Chopra V, Smith BJ, Preiskel HW, et al: Breakaway forces of flat and domed surfaced Magfit implant magnet attachments. Eur J Prosthodont Restor Dent 2007;15:7-12
13. Chung RW, Siu AS, Chu FC, et al: Magnet-retained auricular prosthesis with an implant-supported composite bar: a clinical report. J Prosthet Dent 2003;89:446-449
14. Takahashi T, Fukuda M, Funaki K, et al: Magnet-retained facial prosthesis combined with an implant-supported edentulous maxillary obturator: a case report. Int J Oral Maxillofac Implants 2006;21:805-807
15. Burns DR, Unger JW, Elswick RK Jr, et al: Prospective clinical evaluation of mandibular implant overdentures: Part I—retention, stability, and tissue response. J Prosthet Dent 1995;73:354-363
16. Chan M, Johnston C, Howel R, et al: Prosthetic management of the atrophic mandible using endosseous implants and overdentures: a six-year review. Br Dent J 199;179:329-337
17. Naert I, Gizani S, Vuylsteke M, et al: A 5-year prospective randomized clinical trial on the influence of splinted and unsplinted oral implants retaining a mandibular overdenture: prosthetic aspects and patient satisfaction. J Oral Rehabil 1992;26:195-202
18. Naert I, Quirynen M, Hooghe M, et al: A comparative study of splinted and unsplinted Branemark implants in mandibular overdenture therapy. J Prosthet Dent 1994;71:486-492
19. van Waas M, Kalk W, van Zetten B, et al: Treatment results with immediate overdentures: an evaluation of 4.5 years. J Prosth Dent 1996;76:153-157
20. Walmsley A, Brady C, Smith P, et al: Magnet-retained overdentures using the Astra dental implant system. Br Dent J 1993;174:399-404
21. Walmsley A, Frame J: Implant supported overdentures-the Birmingham experience. J Dent 1997;25(Suppl. 1):543-547
22. 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
23. Riley M, Williams A, Speight J, et al: Investigations into the failure of dental magnets. Int J Prosthodont 1999;12: 249-254
24. Gillings B: Magnetic retention for complete and partial overdentures. Part I. J Prosthet Dent 1981;45:484-491
25. Akaltan F, Can G: Retentive characteristics of different magnetic systems. J Prosthet Dent 1995;74:422-427
26. Highton R, Caputo A, Matyas J: Retentive and stress characteristics for a magnetically retained partial overdenture. J Oral Rehabil 1986;13:443-450
27. Cerny R: The reaction of dental tissues to magnetic fields. Aus Dent J 1980;25:264-268
28. Yiu E, Fang D, Chu F, et al: Corrosion resistance of iron-platinum magnets. J Dent 2004;32:423-429
29. Chu FC, Deng FL, Siu AS, et al: Implant-tissue supported, magnet-retained mandibular overdenture for an edentulous patient with Parkinson's disease: a clinical report. J Prosthet Dent 2004;91:219-222
30. Hargraves A, Foster M: Hydrocryl: an aid to retention? J Dent 1976;4:33-41
31. Bates J: Retention of cobalt-chromium partial dentures. Dent Prac Dent Res 1963;14:168-171
32. Lehmann K, Arnim F: Studies on the retention forces of snap-on attachments. Quintessence Dent Technol 1978;2:45-48
33. Laird W, Grant A, Smith G: The use of magnetic forces in prosthetic dentistry. J Dent 1981;9:328-335
34. Highton R, Caputo A, Pezzoli M, et al: Retentive characteristics of different magnetic systems for dental applications. J Prosthet Dent 1986;56:104-106
35. Wisser W, Coca I, Ruppel-Schönewolf K: The design of root keepers for magnet retained prostheses. ZWR 1996;7:374-378
36. Wirz J, Schmidli F: Magnetic anchor in corrosion test. Quintessenz 1990;41:879-886
37. Setz J, 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