Evaluation of the attractive force of different types of new-generation magnetic attachment systems

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Statement of problem. Rare earth magnets have been used in prosthodontics, but their tendency for corrosion in the oral cavity and insufficient attractive forces limit long-term clinical application.

Purpose. The purpose of this study was to evaluate the attractive force of different types of new-generation magnetic attachment systems.

Material and methods. The attractive force of the neodymium-iron-boron (Nd-Fe-B) and samarium-cobalt (Sm-Co) magnetic attachment systems, including closed-field (Hilop and Hicorex) and open-field (Dyna and Steco) systems, was measured in a universal testing machine (n=5). The data were statistically evaluated with 1-way ANOVA and post hoc Tukey-Kramer multiple comparison test (α=.05).

Results. The closed-field systems exhibited greater (P<.001) attractive force than the open-field systems. Moreover, there was a statistically significant difference in attractive force between Nd-Fe-B and Sm-Co magnets (P<.001). The strongest attractive force was found with the Hilop system (9.2 N), and the lowest force was found with the Steco system (2.3 N).

Conclusions. The new generation of Nd-Fe-B closed-field magnets, along with improved technology, provides sufficient denture retention for clinical application. (J Prosthet Dent 2011;105:203-207)

Clinical Implications

The new generation of magnets provides adequate retention for removable dental prostheses retained by either natural teeth or osseointegrated implants.

Due to the development of permanent magnetic substances, such as rare earth samarium-cobalt and neodymium-iron-boron, magnetic attachments have generated renewed interest in dentistry.[1-3] Their applications have included anchoring dentures,[4] overdenture retention,[5,6] the delivery of force to teeth by intrusion, extrusion,[7] the movement of teeth along an archwire,[8] and in functional appliances[9-11] and orthopedic expansion.[2,12,13] Their popularity is related to their small size and strong attractive forces, attributes that allow placement within prostheses without being obtrusive intraorally.[3] Despite their many advantages, which include ease of cleaning, ease of placement for both dentist and patient, automatic reseating,[3] a decrease in horizontal stress transmission,[14] and retention that is not reduced with use, magnets have poor corrosive resistance when exposed to oral fluids and, therefore, require encapsulation within a relatively inert alloy with soft magnetic properties, such as stainless steel or titanium.[2,3]

Magnetic materials may be defined as either soft (easy to magnetize or demagnetize) or hard (able to retain magnetic properties and serve as permanent magnets). Whether a material is hard or soft depends on whether it retains its magnetic prop-

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erties after the removal of an applied magnetic field.[3,15]

A variety of magnetic systems (open and closed) is available.[3,15-17] Attachment of closed-field magnets is more efficient because both the north and south poles are used to attract the keeper (in open-field systems, only 1 pole is used), and the keeper can contain magnetic flux. Although these systems generally provide a higher retentive force than a similarly sized open-field system, the retention decreases rapidly with increasing separation.[3,16] Freedman[18] used the repulsion of like poles of aluminum-nickel-cobalt (Al-Ni-Co) magnets to assist in the retention of complete dentures. However, their use was discontinued in dental applications because of constant repelling forces, which could cause bone resorption, and because of the large bulk needed for adequate magnetic strength. Behrman[19] used polytetrafluoroethylene-coated platinum-cobalt (Pt-Co) magnets, which were surgically implanted in the mandible, to approximate a similar magnet in the complete denture for retention and stability. However, their large size limited their usefulness.

Essential improvements came with the introduction of rare earth elements. Samarium-cobalt (Sm-Co) rare earth alloy was developed in the late 1960s.[15,16,20] The primary magnetic material currently in use is the rare earth material neodymium-iron-boron (Nd-Fe-B) that was developed in the mid 1980s.[15,21] Boron, the third element, was added to increase the fundamental stability of the crystalline structure.[20] Both Sm-Co and Nd-Fe-B magnets offered an improvement in energy density, which gives an indication of the power of a magnet. The larger the energy density value, the greater the flux produced by a magnet of a given volume.[3] However, attractive force and reseating force were not significantly increased clinically.[16] The attractive force produced by a magnet was between 1 and 4 N; however, corrosion resulted in significant retention losses. Therefore, these forces were not enough to retain dentures when compared to other attachment systems. Currently, new technology has enabled the production of rare earth magnets with improved corrosion resistance, smaller sizes, and stronger attractive forces. New-generation magnets have laser-welded coatings that protect against corrosion and strong attractive forces of approximately 10-12 N, despite their small sizes.

Corrosion of magnetic attachments is caused by 2 different mechanisms: corrosion of the magnet due to the breakdown of the encapsulating material and corrosion of the magnet due to diffusion of moisture and ions through the epoxy seal.[3,15] To prevent corrosion of the magnets, a shield ring made of stainless steel (SUS447J1 or SUS316L) or titanium is welded to the boundary between the cup and disk yokes with the use of a laser beam in a laser-welding technique.[3]

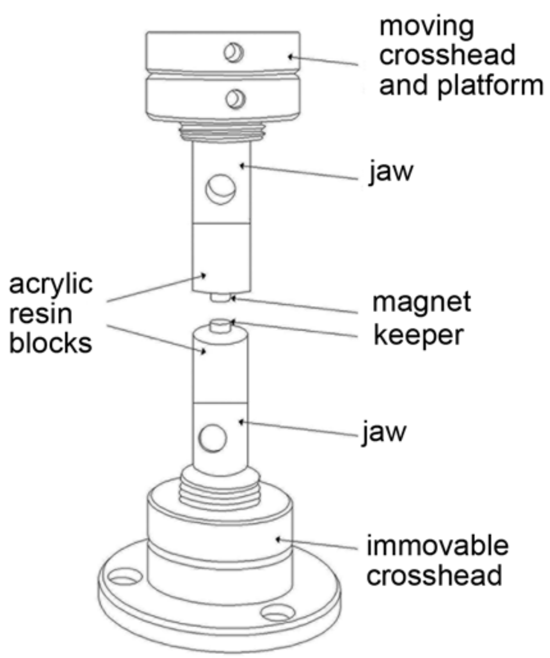
The purpose of this study was to evaluate the attractive force of different types of new-generation rare earth magnets. The null hypothesis was that the new-generation magnets would not produce sufficient retention for prostheses.

MATERIAL AND METHODS

Four types of magnetic attachment systems (Hilop 5513, Hicorex 3513, Dyna 500g, and Steco U.00.01. T570-titanmagnetics) were selected for this study (Table I). Forty acrylic resin blocks (Vertex Orthoplast; Vertex-Dental BV, Zeist, the Netherlands) were prepared with dimensions of 20 × 20 × 20 mm, similar in size to the jaws of the universal testing machine (Lloyd LF Plus; Lloyd Instruments Ltd, Fareham, UK). Magnetic attachments were embedded in the center of acryl-

TABLE I. General properties of magnetic attachments

	Rare Earth Magnet	Magnetic Field	Dimensions (Magnet and Keeper)	Use	Manufacturer
Hilop	Nd-Fe-B	Closed field	5.5 × 1.3 mm 5.5 × 0.8 mm	Sectional denture and obturator	Hitachi Metals, Tokyo, Japan
Hicorex	Nd-Fe-B	Closed field	3.5 × 1.3 mm 3.5 × 0.8 mm	Sectional denture and obturator	Hitachi Metals
Dyna	Nd-Fe-B	Open field	4.8 × 2.7 mm 4.8 × 5.7 mm	Root and implant	Dyna Dental Engineering, Bergen, Holland
Steco	Sm-Co	Open field	5.7 × 12.8 mm 5.7 × 5.7 mm	Root and implant	Steco-system-technic GmbH, Hamburg, Germany



1 Schematic diagram of assembly for measuring attractive force.

Table II. Mean attractive force and SD of each group

	Manufacturer's Purported Value (N)	Mean Value (N)	SD
Hilop	12.2	9.2	0.2
Hicorex	4.8	4	0.3
Dyna	5.1	4.2	0.9
Steco	3	2.3	0.2

ic resin blocks, which are purported by the manufacturer to have no effect on the force delivered by the magnet. The embedment depth was determined by the notches in the attachments, which are designed to provide retention to the acrylic resin denture. The blocks were subsequently fixed to the jaws of the universal testing machine with a 10-N load cell (Lloyd LF Plus; Lloyd Instruments Ltd) with an adhesive resin (Super Bond; Sun Medical Co, Shiga, Japan).

The attractive forces of the attachment systems were measured using a universal testing machine at a crosshead speed of 50 mm/min (Fig. 1). For each attachment system, the attractive force was measured by attaching the magnetic attachments (magnets and keepers) for 5 different attachments. The data collection began with a distance of zero. For each attachment system, the attractive forces were measured 10 times, and the data were averaged. The mean value and standard deviation of the specimens were statistically evaluated for each system using 1-way ANOVA and the post hoc Tukey-Kramer multiple comparisons test (α=.05).

RESULTS

The mean value of attractive forces was 10% to 20% lower compared to the forces provided by the manufacturers (Table II). The ANOVA demonstrated that significant differences (P<.001) were found between measurement results and values provided by manufacturers for attractive forces (F=616.8 and df=3) (Table II).

The closed-field systems demonstrated greater attractive forces than the open-field systems (P<.001). In addition, there was a statistically significant difference in attractive force between Nd-Fe-B and Sm-Co magnets (P<.001). The strongest attractive force was measured in the Hilop system. The Dyna and Hicorex systems exhibited similar attractive forces; however, the Steco system was shown to have the lowest attractive force value. There was no significant difference in attractive force between the Dyna and Hicorex systems (P=.7).

DISCUSSION

The results of the study support rejection of the null hypothesis, because satisfactory retention was found in the Hilop magnetic attachment system, which demonstrated an attractive force of 9.2 N. The retentive capacity of the Hicorex and Dyna magnetic systems may be better for clinical use because, compared to the Hilop system, they are smaller. Clinical experience with magnetic retention suggests that attachments that provide 5 N of retention supply adequate retentive force (for a single attachment, 4 to 10 N[16]) for complete dental prostheses, although some patients may have difficulty removing their dentures when more than 4 magnetic units are used.[5,16] The attractive force of magnetic retainers must be in excess of the displacing force to maintain the denture position in its basal seat area. Gillings[16] stated that such displacing forces may be as low as 0.23 to 0.54 N for a maxillary denture, although much greater values of approximately 5 N have also been suggested.

Chung et al[14] evaluated retention characteristics of attachment systems (both precision and magnetic attachments). The authors found that magnetic attachments showed lower retention than precision attachments. However, according to Gillings,[5] and contrary to results found with magnetic attachments, a significant reduction in the retentive forces of precision attachments was seen after 500 cycles of insertion and removal. In addition, Ortegon et al[22] reported that nonparallel implants and nonparallel attachments resulted in reduced retention values and uneven wear or permanent deformation on the lateral aspect of the attachment after cyclic testing. However, magnetic attachments transmit lower forces to the teeth than other types of attachments. Surface abrasion, due to wear caused by intraoral eccentric movements, does not affect their retentive force significantly. Moreover, magnets have more constant retentive properties and are less susceptible to fatigue than stud attachments.[21] Magnets reduce lateral and rotational stresses to the abutment tooth or implant in function.[16] Neodymium-iron-boron (Nd-Fe-B) provided 20% stronger magnetic force per unit volume than the Sm-Co alloy.[3,16,20] In the current study, Nd-Fe-B magnets produced greater attractive force than Sm-Co magnets, a finding that is consistent with results of prior reports.

Various investigators have used different crosshead speeds to measure attractive forces. Yiu et al[20] used a 2 mm/min crosshead speed, and Watanabe et al[1] used a 5 mm/min speed; however, both Chung et al[14] and Akaltan and Can[16] used a crosshead speed of 50 mm/min. Akaltan and Can[16] also tested a 5 mm/min separation speed. The authors stated that a fast separation speed caused a decrease in the attractive force values of all magnetic systems. A fast speed (50 mm/min) was considered more appropriate for use in the current study because it more closely simulated the velocity of the mandible during mastication.[16,17]

Several investigators[1,4,14,20] used 5 specimens in each test group. Akaltan and Can[16] evaluated retentive characteristics of magnets by using 7 specimens in each group. A significant limitation of the current study was that no power analysis was used to determine sample size. The use of 5 specimens per group was based on previously mentioned studies.

In the current study, open-field and closed-field systems were evaluated. According to Akaltan and Can,[16] the closed-field system demonstrated greater retentive force than the open-field system. When the 2 poles of a magnet are connected by any ferromagnetic material, such as stainless steel, the external magnetic flux field is shunted through the keeper because this is the path of least resistance. This procedure not only eliminates much of the external magnetic flux field, but also makes the attachment more efficient by using both north and south poles.[16] However, Lewandowski et al[17] stated that no difference existed in breakaway force between open-field and closed-field systems. As reported in the study by Akaltan and Can,[16] it was observed in the current study that the closed-field systems demonstrated greater attractive force than the open-field systems. The Dyna attachment had an attractive force similar to that of the Hicorex. However, the Dyna is larger than the Hicorex, and attractive force is directly proportional to magnet dimension. The greater the volume of the magnetic attachment, the more attractive force is generated. However, sufficient attractive force in minimum dimensions is required in prosthodontics. According to the manufacturer's purported value, the Hilop system has a strong attractive force. The Hicorex system is of smaller dimensions and has a satisfactory attractive force. Moreover, there is an inverse proportion between dimension and corrosion resistance of the magnetic attachment.

One of the problems associated with magnetic stainless steel is a lack of corrosion resistance when used in the oral environment, especially when in contact with other types of dental alloys. The acceleration of corrosion is probably due to galvanic corrosion in the presence of different types of metals.[20] Furthermore, many concerns have been raised about the possible cytotoxicity of these corrosion products and their biologic consequences with respect to oral tissues.[2] Further work is required to answer the question as to whether laser-welding procedures will arrest the corrosion completely.

Clinicians should consider using magnets, not only because of ease of cleaning, ease of placement, and automatic reseating of the magnetic attachments, but also because using magnets results in stable retention[3] and reduced lateral and rotational stresses.[14]

CONCLUSIONS

Within the limitations of this study investigating attractive forces of different types of new-generation magnetic attachment systems, it was indicated that new-generation magnets could produce sufficient retention (4-10 N) for prostheses. Furthermore, Nd-Fe-B and closed-field magnets produce significantly greater attractive forces than Sm-Co or open-field magnets.

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Noteworthy Abstracts of the Current Literature

The effect of nano-structured alumina coating on resin-bond strength to zirconia ceramics

Jevnikar P, Krnel K, Kocjan A, Funduk N, Kosmac T.
Dent Mater 2010;26:688-96.

Objectives. The aim of this study was to functionalize the surface of yttria partially stabilized tetragonal zirconia ceramics (Y-TZP) with a nano-structured alumina coating to improve resin bonding.

Materials and Methods. A total of 120 densely sintered disc-shaped specimens (15.5 ± 0.03 mm in diameter and 2.6 ± 0.03 mm thick) were produced from biomedical-grade TZ-3YB-E zirconia powder (Tosoh, Tokyo, Japan), randomly divided into three groups of 40 and subjected to the following surface treatments: AS − as-sintered; APA − airborne-particle abraded; POL − polished. Half of the discs in each group received an alumina coating that was fabricated by exploiting the hydrolysis of aluminium nitride (AlN) powder (groups AS-C, APA-C, POL-C). The coating was characterized using scanning electron microscopy (SEM), atomic force microscopy (AFM), and transmission electron microscopy (TEM). The shear-bond strength of the self-etching composite resin (RelyX Unicem, 3M ESPE, USA) was then studied for the coated and uncoated surfaces of the as-sintered, polished and airborne-particle abraded specimens before and after thermocycling (TC).

Results. The SEM/TEM analyses revealed that the application of an alumina coating to Y-TZP ceramics created a highly retentive surface for resin penetration. The coating showed good surface coverage and a uniform thickness of 240 nm. The resin-bond strength to the groups AS-C, APA-C, POL-C was significantly higher than to the groups AS, APA and POL, both before and after TC ($p \leq 0.05$). During TC all the specimens in the POL and AS groups debonded spontaneously. In contrast, the TC did not affect the bond strength of the AS-C, POL-C and APA-C groups.

Conclusion. A non-invasive method has been developed that significantly improves resin-bond strength to Y-TZP ceramics. After surface functionalization the bond survives thermocycling without reduction in strength. The method is relatively simple and has the potential to become an effective conditioning method for zirconia ceramics.

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