Magnets in Dentistry

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ABSTRACT

Magnets have generated great interest within dentistry. They have been used for various applications in orthodontics and prosthodontics. Earlier use of magnets was limited due to the unavailability of small size magnets, but after the introduction of rare earth magnets and their availability in smaller sizes, their use has increased considerably. They can be placed within prostheses without being obtrusive in the mouth. Their main use in orthodontics has been for tooth movement and in prosthodontics has been in maxillofacial prosthesis and in overdentures as retentive aids. This article reviews the types of magnets available and their application in maxillofacial prosthesis and overdentures, followed by other advantages and disadvantages.

Key words: Rare earth magnets, Permanent magnets, Alnico, Platinum-Cobalt, Chromium-Cobalt-Iron, Cobalt- Samarium and Neodymium- Iron-Boron, maxillofacial prosthesis, overdentures and orthodontics

Introduction

Magnets have generated great interest within dentistry. They have been used for various applications in orthodontics and prosthodontics. Earlier, use of magnets was limited due to the unavailability of small sized magnets, but after the introduction of rare earth magnets and their availability in smaller sizes, their use has increased considerably. They can be placed within prostheses without being obtrusive in the mouth. Their main use in orthodontics has been for tooth movement and in prosthodontics has been in maxillofacial prosthesis and in overdentures as retentive aids. This article reviews the types of magnets available and their application in maxillofacial prosthesis and overdentures, followed by other advantages and disadvantages.

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Magnets have generated great interest within dentistry, and their applications are numerous. The 2 main areas of their use are orthodontics and removable prosthodontics.[1,2] Magnets which were initially used were bulky, and there were concerns raised about their possible toxic effects. However, the current available literature evaluating magnetic fields shows no evidence of any direct or acute toxic effects. Hopp M, Rogaschewski S, Groth T through their study found that samarium–cobalt magnets had a strong tendency for corrosion and showed considerable cytotoxicity. Neodymium–iron–boron magnets had a lesser tendency for corrosion and were only moderately cytotoxic, but coating samarium–cobalt magnets with tin or titanium rendered the material non-toxic.[3] Improved safety with better coating and the introduction of rare earth magnets led to a dramatic reduction in magnet size and stimulated further interest in the field of prosthodontics.[4,5]

The reason for the popularity of magnets is related to their small size and strong attractive forces; these attributes allow them to be placed within prostheses without being obtrusive in the mouth. Despite their many advantages, which include ease of cleaning, ease of placement for both dentist and patient, automatic reseating, and constant

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retention with number of cycles, magnets have poor corrosive resistance within oral fluids and, therefore, require encapsulation within a relatively inert alloy such as stainless steel or titanium. When such casings are breached, contact with saliva rapidly brings about corrosion and loss of magnetism.[6]

Classification of Magnets

There has been no definite classification of magnets given in the literature. Hence, we have tried to combine different types mentioned in various articles, and an effort has been made to develop a simplified classification system for magnets.

A. Based on Alloys used
- Those containing cobalt Examples are Alnico, Alnico V, Co-Pt, Co5Sm
- Those not containing cobalt Examples are Nd-Fe-B, samarium iron nitride

B. Based on ability to retain magnetic properties (intrinsic coercivity or hardness)[6]
- Soft (easy to magnetize or demagnetize) (less permanent)
  Examples are: Pd-Co-Ni alloy, Pd-Co alloy, Pd-Co-Cr alloy, Pd, Co-Pt alloy, Magnetic stainless steels, Permendur (alloy of Fe-Co), Cr-Molybdenum alloy.
- Hard (retain magnetism permanently).
  Examples are: Alnico alloys, Co-Pt, Co5Sm, Nd-Fe-B.

C. Based on surface coating (materials may be stainless steel, titanium or palladium)
- Coated,
- Uncoated

D. Based on the type of magnetism
- Repulsion,
- Attraction

E. Based on type of magnetic field[6]
- Open field,
- Closed field
  – Rectangular closed-field sandwich design,
  – Circular closed-field sandwich design,

F. Based on number of magnets in the system
- Single,
- Paired.

G. Based on the arrangement of the poles
- Reversed poles,
- Non-reversed poles.

Magnetic materials can be divided broadly into two groups, “hard” and “soft,” based on their magnetic properties. The hard magnetic materials possess a large remanence and coercivity and are difficult to magnetize and demagnetize. The hard magnetic materials are, therefore, used for permanent magnets in devices such as motors, loudspeakers, and in a variety of household and industrial devices. The soft magnetic materials have low permeability and low coercivity and are easily magnetized and demagnetized.

Naturally occurring permanent magnetic materials are ferromagnetic nickel and cobalt. Some alloys of other elements such as manganese or chromium can be made ferromagnetic. The ferromagnetic metals combine with other metals or with oxides to form ferromagnetic substances. Although many materials could be listed as magnetic, only a few have gained commercial acceptance because of the requirement for high induction, high resistance to demagnetization, maximum energy production, and low cost.

Permanent magnets that have found applications in dentistry include alnico, platinum-cobalt, chromium-cobalt-iron, cobalt-samarium and neodymium-iron-boron.

Alnico Magnets

Alnico magnets were the first type of permanent magnets to be used for biomedical purposes.[7] Alnico magnets are alloys based on cobalt, aluminum, nickel, and iron.[5] The alnicos are two phase alloys, consisting of a strong ferromagnetic phase and a paramagnetic phase. Since these magnets have low coercivity, they must be protected from the adverse repelling fields as this could partially demagnetize the magnets.[8]

Cobalt-Platinum Magnets

Cobalt-platinum magnets were available at the same time as Alnico magnets. They were discovered in the 1930s by Jellinghaus and were made available in the 1950s.[7] They consist of equal percentages of cobalt and platinum, which forms a continuous solid solution to produce an isotropic magnet. They had improved properties and corrosion resistance compared with the Alnicos available at that time. Despite their superior properties, they did not gain widespread use in medical or dental applications because of their high cost.[7,9]

Chromium-Cobalt-Iron Magnets

The chromium-cobalt-iron permanent magnet alloys were developed by Kaneko *et al*, in 1971. The metallurgy and magnetic properties of these alloys are remarkably similar to those of the Alnicos. However, unlike the Alnicos, these alloys are cold formable at room temperature. The fact that these alloys can be cold worked enabled Kawata and Takeda in 1970 to fabricate magnetic orthodontic brackets, which were then used in the maxillary and mandibular arches to move teeth.[10]

Ferrite Magnets

Ferrite magnets are sometimes called as ceramics. They are electrically non-conductive magnets, which are manufactured since 1954. It consists of iron oxides such as hematite (Fe_2O_3) or magnetite (Fe_3O_4) with traits of other metal oxides. Hard ferrite magnets are not commonly used in biomedical applications. They are more resistant to demagnetization than the Alnico materials, which make them suitable for use in complex-shaped magnets.[7]

Though with respect to other magnets they provide less energy, they are very stable. They have high permeability and in saturated state, they conduct a magnetic flux, which allows them to store stronger magnetic fields than iron.

Rare Earth Magnets

Rare elements consist of group of seventeen elements having atomic numbers 21, 39, and from 57 to 71. The elements having atomic numbers between 58 and 71, are called as lanthanide. These elements have strong affinity for the non-metallic elements, due to which they are used for producing alloys, which are used in metallurgical industries.

Made from alloys of rare earth elements, rare earth magnets are strong permanent magnets. As they are stronger than ferrite or alnico magnets, the magnetic field produced by them is also higher.

Rare earth magnets are capable of producing high forces relative to their size due to the property of magneto crystalline anisotropy.[5,11] This property allows single crystals to be preferentially aligned in one direction (along the C-axis), which increases the magnetism.[5] The rare earth magnets demonstrate significant improvements in the maximum energy product (BHmax), which has led to a dramatic reduction in the size of magnets required to produce a particular magnetic flux.[11,12] Another advantageous characteristic of the rare earth magnets is their very high coercivity, compared to Alnico magnets. High coercivity means these magnets have a superior ability to resist demagnetization.

Samarium-Cobalt Magnets

Samarium-cobalt magnets (SmCo5) are powerful rare earth magnets composed of samarium and cobalt. These are brittle magnets and hence prone to crack and chipping. Samarium magnets can be used for high temperature applications. Samarium-cobalt (SmCo) magnets were developed in the 1960s and 1970s.[13,14] Various intermetallic compounds of samarium-cobalt are possible including SmCo3, Sm2Co7, SmCo5, and Sm2Co17.[5,7,13,14] These magnets are characterized by high saturation magnetization and Curie temperature.[13] They are more costly than other rare earth magnets but are chosen in preference to those with a lower Curie temperature, such as Neodymium, when they are needed for high temperature applications.[7]

Neodymium-Iron-Boron Magnets

Although cobalt-samarium had the desired properties of a hard magnetic material, it had some drawbacks like it was expensive. In addition, the supply of cobalt was subject to political conditions in the countries in Africa that produced it, notably Zaire, this too affected its price. This precipitated a search for cobalt-free magnetic materials, and this led to the development of iron-based alloys of the general composition $R_2Fe_{14}B$, where R is a Rare earth, usually Neodymium. This new alloy had magnetic properties superior even to those of cobalt-samarium, with the energy product being as high as $341 KJ/m^3$.

Neodymium-iron-boron (NdFeB) magnets arose in response to this need and were first announced in 1984 by two independent groups.[15] $Nd_2Fe_{14}B$ is the basic compound, but various partial substitutions and modifications are commonly made. This type of rare earth magnet has an extremely high magnetic saturation, good resistance to demagnetization, and the highest value of energy production. Their excellent magnetic properties allowed the production of very small magnets.[11] They are less costly to produce than Sm-Co alloys, and hence are now the main rare earth permanent magnet in use today.[7]

The main limitation of the neodymium magnet is that it has a low Curie temperature, as low as 300°C, whereas SmCo alloys have excellent stability, with a Curie temperature as high as 725°C.[14] This is a distinct disadvantage for dental applications as magnets are embedded in acrylic appliances. On curing, methyl methacrylate reaches a temperature of between 80 and 90 degrees. This could cause a significant amount of flux loss due to the exothermic setting reaction of the acrylic. It is important to ensure that the loss of flux and, therefore, force is taken into account when preparing these magnets for dental applications.[11] The addition of 6% cobalt, however, raises the Curie temperature by 100K. Such alloys, therefore, are not entirely cobalt-free, but the amount of cobalt is greatly reduced from that in cobalt samarium alloys.

Samarium-Iron-Nitride Magnets

Samarium-iron-nitride permanent magnets are a promising candidate for future applications. These magnets may be a superior choice to NdFeB magnets in the future, because they have high resistance to demagnetization, high magnetism, and better resistance to temperature and corrosion.[6] This material is still under development, but could become available for medical and dental applications in the future.

Use of Magnets in Maxillofacial Prosthesis

From the time of the formation of the American Academy of Maxillofacial prosthetics in 1952 until now, the treatment and rehabilitation of patients with cancer of the head and neck and the importance of maxillofacial prostheses has increased several times. But, still there are many challenges in every phase of construction, as well as in the retention of maxillofacial prostheses.

Magnets have been effectively used for the retention, maintenance, and stabilization of combined maxillofacial prostheses, and they are effective for this purpose.[16,17]

Advances in maxillofacial materials and techniques have been remarkable in the past decade. To minimize the psychological trauma that will be associated with the facial disfigurement, a maxillofacial prosthodontist should meet the challenges associated with the fabrication of a prosthesis, which meets the functional and esthetic requirements of the patient so as to help him lead a normal social life.[17]

The most convenient size of magnet can be chosen according to the size of the defect and in any diameter that is needed.[18]

Prosthesis insertion and retention of prostheses for patients with large intraoral defects can be improved if the prosthesis is divided into an oral and an obturator section. If necessary, the obturator can be further divided into two or more parts. The location of the contacting surfaces of prosthesis sections should be placed for ease in construction and insertion. The undercut in the defect should not prevent insertion of any section, and the esthetics of the restoration should not be compromised by the division. A sectional prosthesis can be used for patients with large maxillary defects. Two magnetic pairs are commonly used for connecting the sections. The magnets are embedded in the respective contacting surfaces at a depth of 0.5 mm. Because Sm-Co magnets are small, the obturator can be made hollow to reduce its weight. The size of ferrite or alnico magnets often prevents use of a hollow obturator.

Use of Magnets in Overdentures

An overdenture may be defined as a removable prosthodontic appliance, either complete or partial, that restores missing dentition and is fabricated to fit over retained teeth and/or roots that are properly prepared.[19] This definition can be modified to fit within the framework of dental implants. So, the overdenture is also a special denture that fits over dental osseo-integrated fixtures.

Magnetically retained overdentures are virtually maintenance-free and inexpensive to fabricate, and the technique lies within the scope of every dentist. They have numerous advantages and little or no disadvantages. The book of Brewer and Morrow (1976) describes that overdentures have been in use since 1847.

The major purpose of an overdenture is preservation of the alveolar bone by retaining teeth or/and roots underneath. Magnetically retained overdentures transfer no detrimental lateral forces to those supporting elements that help in maintaining favorable clinical situation.

The use of magnetic materials as an aid to denture retention is not new. The use of magnets to provide retention by direct attraction followed, with the placement of a magnet beneath the mucosa, embedded in the bone, and the opposite pole magnet in the fitting surface of the denture base (Behrman 1960).[20] This procedure failed as the embedded magnets came to surface contact through the mucosa (Toto, 1962).[21] The surgical procedure was also not easy.

Generally, several attempts were made to apply magnetic force to help making prosthesis, but only when the rare earth cobalt-samarium magnets were developed has they received adequate attention. Small size in connection with comparatively strong force made this idea very attractive and useful in prosthetics.

Samarium-cobalt is the best known and most widely used in dental applications. It delivers twice the magnetic field strength of previously used Alnico and platinum-cobalt magnets. More importantly, rare earth magnets deliver high attractive forces in very small sizes-a prime consideration in dental appliances.[22]

Their simplicity of use, cost-effectiveness, and kindness to supporting abutment teeth have all contributed to a renewed interest in magnetically retained prosthetic appliances.

In addition, magnetic overlay dentures are often used in conjunction with osseo-integrated implant systems, mandibular staple implants, sub-periosteal implants, and bar-splinted overdenture abutments that have been decoronated after endodontic therapy.[22]

The simplicity and ease with which rare earth minimagnet-retained prosthetic appliances may be fabricated has contributed to their rapidly expanding popularity.

Roots with as little as 3 mm of bone support are adequate for use as abutments with magnetic appliances.

Magnetic systems do not direct undue stress to root-abutments, as mechanical "lock-on" attachments do. Magnets do not resist lateral movement of overlay appliances; they merely slide across the faces of the keepers, the ferromagnetic inserts cemented into the abutment tooth.[22]

Initially,the repellent force of like magnetic poles was harnessed from open-field AlNiCo alloys embedded in the base of upper and lower dentures, so that the repellent forces would keep dentures on the residual ridges. However, this approach achieved little popularity because the force was weak, and the direction of the force was just as likely to repel the dentures out of the mouth. A more popular method was to attach a ferromagnetic metal keeper (generally made of stainless steel) to the tooth or implant for attraction by a magnet embedded in the nearby denture base; this arrangement is known as a magnet–keeper unit.[23]

Treatment planning and fabrication of magnetic overdentures is quite simple.[22]

Appropriate teeth are designated to be retained as abutments.

Following endodontic and periodontal therapy, the abutment teeth are decoronated to the gingival level.

To these root-abutments are cemented the keepers.

Following insertion of the keepers, final impressions are made in the usual fashion for fabrication of the overdenture. It is best not to incorporate magnets into the appliance at this stage. Rather, it has been found preferable to deliver the overlay denture to the patient without magnets, perform any needed post-insertion adjustments, and have the patient become accustomed to the new prosthesis, minimagnets can then be incorporated at chairside, and the patient can readily appreciate the effectiveness of magnetic retention.[22]

Application of Magnetic Forces in Orthodontics

Magnetic forces have been used in orthodontics for both tooth movement and orthopedic correction with varying degrees of success. The use of magnets for generating orthodontic forces has been a subject of increasing interest.[10]

Magnets for Tooth Movement

The first reported use of magnetic force to move teeth was in 1977 when Kawata and Takeda[10] described a technique of using magnetic brackets of Co-Cr-Fe alloy, bonded to the upper anterior and the lower anterior teeth, for interdental space closure. The "retracting and pushing" force of the maxillary brackets was reported to be 25 - 30 g [f] [0.25 - 0.29 N] and that in the mandibular brackets 20 - 25 g[f] [0.19 0.24 N]. This study was extended one year later with the motive force provided by Co-Sm magnets of almost the same volume as previously. The force delivered was increased to 200 "g wt" [1.96 N]. It was concluded that this new magnetic orthodontic tooth movement system was useful not only for space closure, but also for canine retraction and to correct dislocated, rotated or inclined teeth.[24]

Blechman and Smiley[1] demonstrated the use of Alnico magnets for Canine distalization in two cats. Later, in a pilot study, Blechman[1] reported the successful use of SmCo magnets attached to edgewise appliances for the application of intra- and inter-maxillary forces.[3] He suggested that magnets were superior to inter-maxillary elastics as they do not require patient compliance and the forces between the magnets fall below clinically useful amounts when the teeth are apart negating some of the unwanted side-effects.[4,25]

Muller used small rectangular magnets directly bonded to the labial aspect of the teeth to close diastemas without archwires. The magnets applied 117.5grams of force, but the force was determined by the distance separating the teeth and, therefore, influenced the size of the magnets used.[26] Darendeliler and Joho described a similar concept in their Autonomous Magnetic Arch, which also had no brackets or archwires, but used small, SmCo magnets bonded to each tooth to form a continuous force releasing arch.[27]

Advantages

- Magnets provide both retention and stability.
- Magnets allows for a 24 degrees of abutment divergence, which provides for an easy non-critical path of prosthesis insertion and removal.
- The roots or implants do not need to be parallel.

- Soft tissue undercuts may be engaged.
- Potentially pathologic lateral or rotating forces are eliminated providing maximum abutment protection.
- Enables automatic reseating of the denture if dislodged during chewing.
- If mis-aligned placement occurs, then orthodontic movement of the root will result in correct contact being reached.
- Roots with as little as 3mm of bone support are adequate for use as abutments with magnetic appliances.
- They do not directly induce stress to root abutments.

Disadvantages

- Corrosion of magnetic attachments may occur by two different mechanisms.
  1. Corrosion of the magnet due to the breakdown of the encapsulating material.[5]
  2. Corrosion of the magnet due to diffusion of moisture and ions through the epoxy seal.[5]
- The main problem associated with the use of magnets as retentive devices is corrosion. Both Sm-Co and Nd-Fe-B magnets[6,18] are extremely brittle and susceptible to corrosion, especially in chloride-containing environments such as saliva, and the presence of bacteria increases the corrosion of Nd -Fe-B magnets.
- It is, therefore, necessary to encapsulate or coat the magnets for use in dental applications. However, continual wear of the encapsulating material leads to exposure of the magnet.[6]
- Wear presents in the form of deep scratches and gouges on the surface caused by wear debris and other particles that become trapped between the magnet and the root. Finally, there will be loss of retention provided by the attachment.
- The excessive wear of the magnet may be due to the abrasive nature of the titanium nitride-coated soft magnetic tooth keeper that is used with some implant systems.
- Currently available magnets based on Nd-Fe-B have attractive forces that enable them to provide retention. Problem of corrosion can be overcome with encapsulating materials such as stainless steel, which are effective.

Conclusion

Early attempts at using magnets for intra-oral uses were unsuccessful, mainly because of the large size of magnets at that time and the inadequate forces that they provided. However, since the introduction of rare earth magnets such as samarium-cobalt and Neodymium- iron- boron, it has become possible to produce magnets with small enough dimensions to be used in dental applications and still provide the necessary force.

The development of samarium-iron-nitride may offer better resistance to corrosion. The magnetic denture retention system is not advocated as a replacement for conventional precision retainers but as a useful alternative where, for reasons of convenience, cost, patient motivation or poor prognosis, conventional retainers are unsuitable.

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