

Clinical application of magnets in orthodontics and biological implications: a review

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SUMMARY Over the last decade magnets have been used in orthodontic and dentofacial orthopaedics and attempts have been made to evaluate the biological implications of magnets and magnetic fields during clinical application. This review aims to indicate the advantages and disadvantages of magnets in orthodontics and dentofacial orthopaedics over traditional techniques, and update related clinical experiences. The treatment of impacted teeth and Class II malocclusions by means of magnetic force is favoured and the correction of Class III and open bite malocclusions involving the use of magnets also appears promising. The advantages of magnets over traditional force delivery systems are: frictionless mechanics, when the magnets are in attractive configuration; predictable force levels, no force decay over time and less patient co-operation. However, the size of the magnets can increase the bulk of the appliance and three-dimensional control is limited when the magnets are in a repulsive configuration. In addition magnets used *in vivo* require a coating to prevent corrosion and the possible side effects of corrosive products.

Introduction

The magnets most commonly used in the initial studies in dentistry were made of either aluminum–nickel–cobalt (AlNiCo) or platinum–cobalt (PtCo) alloys. These magnetic alloys were used for fixation of dentures (Freedman, 1953; Thompson, 1964; Winkler, 1967) or maxillofacial prostheses (Nadeau, 1956; Robinson, 1963; Javid, 1971), and were also implanted surgically into the molar regions of edentulous mandibles for retention of complete dentures. This latter procedure was described by Behrman in the 1960s and involved the use of PtCo alloy bar magnets coated with Teflon (polytetrafluoroethylene). Microscopic, roentgenologic and clinical evidence all indicated that magnetism had no deleterious effects on the tissues surrounding the implants and that bone filled the surgical opening, fitting closely to the magnet (Behrman, 1960, 1964). Toto *et al.* (1962, 1963) subsequently reported the findings of a

detailed histological investigation into the reaction of bone and mucous membrane to magnetic implants which revealed that the PtCo alloy itself was harmless to osseous and fibrous tissues.

As the properties of the magnets limited their use in oral environments, there were few further developments after the initial investigations. In the 1970s and 1980s, however, rare earth magnets, samarium–cobalt (SmCo) and neodymium (NdFeB) respectively, with their improved properties (Becker, 1970; Robinson, 1984), brought marked advantages to clinical applications. The result was a growing interest in the use of rare earth magnets as an alternative to traditional attachments and force systems in both prosthetic and orthodontic treatment.

Clinicians are, however, concerned about certain aspects of this new field of application: What are the biological effects of magnets and magnetic fields, are the static magnetic fields

biologically harmful and which are the areas where the magnets have advantages over traditional techniques?

Biological implications

Despite being of primary interest, information on the biological effects of magnets in humans is currently somewhat limited. However, a number of biological investigations have been conducted in various animal species and in cell cultures.

Biophysical properties

One of the first studies on the magnetic properties of the SmCo magnet was reported by Tsutsui *et al.* (1979). They found that the corrosion resistance of the SmCo magnet was similar to that of usual dental casting alloys, but that acid resistance was relatively low. The magnet had virtually no toxic or other negative effects on the tissues. The authors therefore concluded that SmCo magnets could be safely used as a dental material if plated or coated. Another study which investigated the electrochemical properties, corrosive tendencies and reactivity to the oral environment of SmCo and NdFeB revealed the necessity to improve coating methods (Vardimon and Mueller, 1985). In a detailed study, Kitsugi *et al.* (1992) compared the corrosion resistances of SmCo and NdFeB magnets and found that although the corrosive activity of the NdFeB magnet was higher than that of the SmCo magnet, it was necessary to hermetically seal both magnets for dental use. Fibroblasts showed less proliferation in the presence of NdFeB magnetic corrosion products; however, their attachment was not disrupted after an experimental period of 12 hours (Evans and McDonald, 1995). Another study showed that sodium fluoride (NaF) and stannous fluoride (SnF₂) increased the surface roughness of both SmCo and NdFeB magnets (Obatake *et al.*, 1991).

In a retrospective study, Drago (1991) reported that the edges of all magnetic implants used in various clinical prosthodontic procedures showed evidence of tarnish and that the attachment site for the magnets—the magnetic keepers—appeared somewhat corroded, thus

significantly affecting the useful lifespan of intraoral magnets.

Cell culture studies

Investigation of the short-term biological effects of SmCo magnets by exposure of three standard cell lines (JY human lymphocytes, WI-18 human embryonic fibroblasts and LM mouse embryo fibroblasts) to a magnetic field of 50 mT intensity produced by SmCo magnets revealed no significant effects on growth rate or type of cellular response (Esformes *et al.*, 1981). Similarly, NdFeB magnets do not appear to have cytotoxic effects on osteoblast-like cells (UMR-106) (Sandler *et al.*, 1989) and do not significantly affect cell activity in either attractive or repulsive magnetic fields (Papadopoulos *et al.*, 1992). However, by using thymidine and prodine uptake methods, McDonald (1993) found an increased proliferation and systemic activity in fibroblasts in the presence of static magnetic fields generated by SmCo magnets.

The effects of magnetic fields on the growth of human cultured cells have been investigated in several studies. The results showed no significant consequences with respect to DNA synthesis, DNA content, cell shape, surface structure or cell numbers (Sato *et al.*, 1992), or glycolytic activity (Yamaguchi *et al.*, 1993). However, orthodontic magnetic brackets producing a field of 130 G have been shown to influence the oral microbial flora, significantly stimulating the growth of *Candida albicans* in a 24 hour period (Staffoliani *et al.*, 1991).

The biocompatibility of orthodontic magnets in three different states—new, after clinical use and recycled—has also been tested in terms of cytotoxicity. As the cytotoxic effect was highest with the new magnets, less marked with the clinically used ones and smallest with the recycled magnets, the authors concluded that the biocompatibility of SmCo magnets is maintained upon recycling (Bondemark *et al.*, 1994a). In a similar study, two different test methods using cell material showed high cytotoxicity of the uncoated SmCo₅ magnets and negligible cytotoxicity of the uncoated Nd₂Fe₁₄B as well as parylene-coated Sm₂Co₁₇ and Nd₂Fe₁₄B magnets (Bondemark *et al.*, 1994c).

Animal studies

One of the first animal studies investigating the effects of SmCo magnets implanted within the tissues reported no adverse effects in the blood cells (Cerny, 1979); no abnormalities of the tissues around magnetic implants (Cerny, 1980a); and no change in the dental pulp, periodontal and gingival tissues, buccal mucosa or alveolar bone in the presence of a magnetic exposure of up to 95 mT (Cerny, 1980b). Even after implantation of titanium-coated SmCo magnets in dog mandibles for a period of 6 months, Altay *et al.* (1991) found no abnormal healing or osteoblastic activity and no notable difference in cell size, shape or content. These results were similar to those of Bruce *et al.* (1987), who demonstrated that fractured bone units, when exposed to static magnetic fields, showed no histological change but a stronger callus between bone units. Camilleri and McDonald (1993) found no significant difference between the experimental north pole and south pole exposure groups versus a control group with respect to growth pattern or rate of bone deposition in rat sagittal sutures. In a stereological analysis of blood vessels and nerves in magnetically extruded marmoset incisors, Parlange and Sims (1993) found no distinctive differences in blood vessel morphology between the control and experimental samples, and the total luminal periodontal ligament vascular volume was statistically unchanged.

The effects of pulsed electromagnetic fields (PEMF) and static magnetic fields (SMF) on the rate and quality of hard tissue repair after osteotomies have been analysed in guinea pig mandibles. Wound healing was faster in both the PEMF and SMF groups than the controls; increased amounts of bone formation and hard tissue density were also observed in the osteotomy sites (Darendeliler *et al.*, 1993a, 1997). In a related study, the rate of orthodontic upper incisor movement was also evaluated in the presence of PEMF and SMF. The results showed a significant increase in the rate of tooth movement for both PEMF and SMF when compared with the control group. Both experimental groups demonstrated a reduced 'lag phase' between the third and the sixth

day, and an increase in the organization and amount of new bone between the incisors. In blood chemistry and haematological analyses, the PEMF and SMF groups both showed a reduced serum calcium level, probably due to an increased rate of osteogenesis, and an increased white blood cell count, possibly as a response to corrosive products (Darendeliler *et al.*, 1995a).

In contrast, an investigation of the effects of static magnetic fields on bone surface and skin reported by Linder-Aronson and Lindskog (1991) showed a reduction in the number of epithelial cells in the areas where the magnets had been applied and a significant increase in bone resorbing areas after 3 and 4 weeks. Furthermore, contact or close proximity to magnets, coated with acrylic and composite resin, in soft and hard oral tissues resulted in reduced epithelial thickness and resorption of the cortical bone surface adjacent to the magnet (Linder-Aronson *et al.*, 1992).

Studies in patients

As previously stated, there are very few human studies on the biological effects of magnetic fields. Blechman (1985) found no effect on urinary cobalt levels measured at 6 month intervals, whilst Kawata *et al.* (1987) observed no significant changes in ascorbic acid, calcium or citric acid concentrations. Moreover, magnetic fields appear to have no detrimental effect on maxillary buccal mucosal blood flow (Saygili *et al.*, 1992). In another study on seven patients, Bondemark *et al.* (1995) showed that commercially available orthodontic magnets did not cause any histologically detectable change in dental pulp and gingival tissues.

Clinical application of magnets

Review of the literature on the clinical use of magnets reveals a substantial body of data which is summarized here in five separate categories in order to provide a more thorough understanding of the evidence.

Tooth movement

The first magnetic brackets were designed by Kawata *et al.* in 1977. These brackets, made from

iron-cobalt and chrome alloy, were inadequate and were subsequently replaced by rare earth magnets which produced sufficient force to move canines and other teeth (Kawata *et al.*, 1978; Kawata and Matsuga, 1979). In a study conducted in two cats, Blechman and Smiley (1978) used AlNiCo magnets completely coated with fast-curing acrylic to distalize canines over a period of 9 months. This work illustrated that the relatively continuous and consistent force produced by these magnets resulted in a more rapid distalization, was less traumatic and was safe in the oral environment.

After these initial investigations, magnets were used in a variety of configurations in an attempt to emulate conventional orthodontic force application. In a pilot study, Blechman (1985) reported the successful use of SmCo magnets in combination with an edgewise device for the application of intra- and inter-maxillary forces. He reported that magnets were superior to intermaxillary elastics, in that they provided a better control of force and did not require patient cooperation. A similar method has been used with a repelling magnet system in conjunction with a modified Nance appliance for distalization of maxillary molars. The molars can be distalized with a movement rate of 0.75–1 mm per month, even in the presence of second molars, without significant loss of anchorage. However, molar movement is faster (by at least 1 mm/month) in the absence of second molars and results in less anchorage loss. The magnets are reported to be easy to insert and well tolerated, and patient cooperation is not required during the treatment period (Gianelly *et al.*, 1988, 1989; Gianelly, 1991). Bondemark and Kurol (1992), using an analogue system generating 116 grams of repelling force at 1 mm of space, found that molar distalization was mainly due to distal tipping and rotational movements (8.0 and 8.5 degrees, respectively) with no statistically significant skeletal changes.

Bondemark *et al.* (1994b) also compared the effectiveness of magnets and NiTi open coil springs in maxillary molar distalization over a 6 month period. Eighteen patients with Class II malocclusion and deep overbite (age range 12.5–18.3 years) were treated with magnets on

one side and NiTi open coil springs on the contralateral side. Both systems exerted the same force value of 225 grams at the beginning of treatment and in every reactivation; however, the force level on the magnetic side showed a more rapid decrease. The authors reported that the bodily distal molar movement in the NiTi coil spring group was larger than that in the magnet group (mean values of 3.0 mm and 2.4 mm, respectively). The molars also showed distal tipping and rotation (mean 3.5 and 2.5 degrees, respectively) and increased overjet (mean 1.8 degrees) as a result of the reciprocal forces. A similar study in 13 patients was reported by Erverdi *et al.* (1993), who compared a repelling magnetic force of 200 grams with NiTi coil springs; however, the force level between the magnet and coil spring sides was not matched. After an experimental period of 3 months the results indicated that NiTi coil springs were more effective in molar distalization.

Magnets have also been employed in different ways to achieve space closure. In a preliminary study, Müller (1984) used rectangular magnets applying 117.5 grams of attracting force for median diastema closure. In 1987 Kawata *et al.* soldered SmCo magnets plated with chromium and nickel to edgewise brackets for the administration of mesio-distal magnetic forces. In cases involving extraction, the canines were retracted conventionally until the magnetic brackets on the second premolars exerted enough distalization force on the canines. The authors reported that the magnetic method reduced the treatment time, resulting in neither pain nor discomfort, periodontal problems, root resorption or caries.

Darendeliler and Joho (1992) also reported a skeletal and dental Class II case with multiple diastema in which the patient had orthodontic and orthopaedic treatment using only magnetic forces; no arch wires or any other force delivery systems were employed. The diastemas were closed within 6 months using the Autonomous Magnetic Arch, an appliance consisting of small rectangular SmCo magnets forming a continuous force-releasing arch. The Magnetic Activator Device II (MAD II) was used continuously for a further 6 months to correct

the patient's skeletal and dental Class II malocclusion and slight mandibular deviation. The patient reported no discomfort with either of the magnetic appliances.

The use of magnets to extrude a tooth and enhance root eruption in a traumatized case was reported by McCord and Harvie (1984), who extruded the root of a subgingivally fractured incisor by means of SmCo magnets—one fixed to the root and one embedded in a removable partial denture. The guided eruption of an impacted canine was first reported by Sandler *et al.* in 1989; this application came to be increasingly used and has also been successfully applied to unerupted premolars (Sandler and Fearn, 1990; Sandler, 1991). The theory and technique are similar for both these applications. Following surgical exposure of an impacted tooth, a magnet is bonded to the tooth surface and the mucosal flap is sutured in place, completely covering the tooth with its bonded magnet. Guided eruption is achieved by means of a second intraoral magnet embedded in a removable plate and placed in such a way as to attract the sub-mucosal magnet. Vardimon *et al.* (1991a) have described different magnetic arrangements which utilize a vertical magnetic bracket for impacted incisors and canines and a horizontal magnetic bracket for impacted premolars and molars. In addition, Darendeliler and Friedli (1994) have reported the combined use of removable and fixed-type attraction systems for an impacted upper canine in which the fixed part consisted of a magnet-fixed Ballista-type sectional arch. The attracting force in these systems varied from 20.4 to 51 grams at 2.5 mm and was approximately 45 at 1.5 mm (Vardimon *et al.*, 1991a; Darendeliler and Friedli, 1994). The authors concluded that the use of magnets was effective for the eruption of impacted teeth, that treatment time and discomfort were reduced, and that no side-effects were observed. Recently, the treatment of impacted premolars in several members of the same family was reported by Yüksel *et al.* (1995).

The use of magnets has also been reported to retain treated teeth. For example, in a case report by Springate and Sandler (1992), small, thin NdFeB magnets were bonded onto the palatal

surfaces of the upper incisors in order to prevent re-opening of a diastema.

Expansion

In addition to applications involving orthodontic tooth movement, magnets can also be used effectively to achieve a variety of orthopaedic objectives. Repulsive magnetic forces for maxillary expansion were first described by Vardimon *et al.* in 1987. In that initial experiment, one monkey received a bonded expansion appliance (SmCo magnets) exerting 258 grams of indirect force (tooth anchorage); the second received an endosseously pinned appliance (SmCo magnets) with equal, but direct magnetic force and position (bone anchorage); the third received a rapid expansion jackscrew appliance exerting a force of 2033 grams; and the fourth, control animal received a passive sham appliance. The authors reported orthopaedic changes in palatal expansion with magnetic forces. Investigating the induced external root resorption (ERR) and repair process, Vardimon *et al.* (1991b) found that the canine, as a single-rooted tooth, demonstrated a high resistance to ERR whereas multirooted teeth were more susceptible; the root surfaces most affected were the buccal root surface and the furcation area. The authors concluded that, for short-term treatment, the intensity of ERR is probably related to the magnitude of force, whilst for longer treatment periods time becomes the dominant factor.

A clinical study on maxillary expansion with repulsive Sm₂Co₁₇ magnets has been reported by Darendeliler *et al.* (1992, 1994) and Darendeliler and Strahm (1995). Two kinds of Magnetic Expansion Device (MED), bonded in two patients and banded in another four, were used to exert 250–500 grams of force. For a more accurate evaluation, implants were placed in each patient. Following active treatment, the patients were observed during a retention period of 6 months using a Hawley retainer. More pronounced skeletal, versus overall, expansion effects were obtained with the banded MED (16–77 per cent) Stability was adequate after a post-retention period of 12.5 years. The authors indicated that the use of continuous light forces (250–500 grams) could generate dental and

skeletal movements, the degree depending on the patient's status (age, growth, etc.).

Class II

In a study conducted on animals, Vardimon *et al.* (1989) introduced the FOMA II, a functional orthopaedic magnetic appliance which works by protruding the mandible as a result of attraction of anteriorly positioned magnets. This study was conducted in 13 prepubertal monkeys receiving conventional functional (FA), FOMA, FA + FOMA and control appliances for a period of 4 months. The results demonstrated that the functional performance of the FOMA and FA + FOMA was greater in comparison with the FA. The mandibular length showed a statistically significant increase in the treated animals over the untreated ones. Moreover, the incisor proclination was less in animals treated with the magnetic appliances compared with those treated with conventional appliances.

Using a similar method but with repelling magnets, Kalra *et al.* (1989) reported the use of a fixed magnetic appliance for Class II division 1 cases associated with mandibular retrusion and increased lower face height. After 4 months of active treatment with an intrusive force of 90 grams per tooth in 10 patients, a control group of 10 children with similar dentofacial characteristics were chosen to evaluate the effects of this appliance. The authors reported a significant increase in the length of the mandible and a decrease of the mandibular plane angle in children receiving active treatment.

Another functional magnetic appliance, MAD II, was introduced by Darendeliler and Joho for the same purpose (Joho and Darendeliler, 1991; Darendeliler and Joho, 1992, 1993). The appliance design was developed progressively using smaller magnets and reduced force levels. The magnet shape and dimensions were also changed from a rectangular bar (Darendeliler and Joho, 1992) to a triangular prism (Joho and Darendeliler, 1991; Darendeliler and Joho, 1993) and then to cylindrical form (2.5 × 9 mm). The use of attracting magnetic forces, ranging from 150 to 600 grams per side, revealed that a force of more than 500 grams appeared to produce unwanted or exaggerated

dental movement while a force below 200 grams was insufficient to obtain protrusion of the mandible. A force of 300 grams per side was, however, found to be appropriate in patients between the ages of 7 and 12 years for correcting Class II malocclusions by growth modification with only minimal tooth movement. The MAD can be worn full-time, except during meals, since phonation and deglutition are not as limited as with a traditional activator. In order to evaluate the efficacy of the appliance and its dental and skeletal effects, 19 dental deep bite patients treated with a MAD II were compared with 19 non-treated Class II controls (Joho and Darendeliler, 1993). Pre- and post-treatment cephalometric values were compared with the control group, which was matched for age, sex, ANB, Sn-GoGn angle and observation period. The results showed changes in the facial height which were expressed by augmentation of the cranial base/palatal plane angle and the palatal plane/mandibular plane angle, as well as by augmentation of the lower facial height and a decreased anterior-posterior facial height ratio, which were statistically significant. The authors concluded that the MAD II was effective for the treatment of Class II deep bite malocclusions and was accompanied by an almost immediate functional adaptation.

Class III

A FOMA III appliance with two Nd₂Fe₁₄B magnets in a centripetal attractive force configuration exerting both vertical and horizontal force factors in the anterior region was designed by Vardimon *et al.* (1992) for the treatment of Class III malocclusions. Six monkeys received experimental appliances while three others received sham appliances. Over a 4 month period, despite no cephalometric changes at the cranial base level, a marked effect was seen in the midfacial complex with a significant forward movement of the maxillary incisors and first molars. The lack of growth-reducing effect on the mandible was thought to be due to the short experimental period used to determine multi-tissue time-related response of the appliance. The authors recommended

the FOMA III for long-term use at an early deciduous age.

Clinical applications for the MAD III appliance have been reported by Darendeliler *et al.* (1993b) and Luthy-Burhop *et al.* (1995). This activator consists of an upper and lower plate carrying two buccal pairs of attracting magnets placed eccentrically in the sagittal direction in such a way that the mandible is pulled distally and the maxilla mesially. Two cases have been treated successfully with the MAD III—one combined with a MED and the other combined with a Delaire facemask.

Open bite

The first clinical application in this field, the Active Vertical Corrector, was introduced by Dellinger in 1986. Bearing posterior repelling magnets, this appliance was considered as an 'energized' bite block, removable or fixed, with the aim of achieving intrusion of the posterior teeth by generating 700 grams of force per magnetic unit. The author reported that the four cases treated with this appliance showed little tendency towards re-eruption of the molars, but some labial or lingual tipping of the maxillary incisors was observed. The appliance was recommended for both adults and children, although a more rapid correction was observed in growing children.

The efficiency of magnetic bite blocks has been studied in growing and non-growing baboons and compared with non-magnetic bite blocks (Woods and Nanda, 1988, 1991). In growing animals intrusion effects on the posterior teeth, forward maxillary displacement and significant eruption of anterior teeth for both groups have been observed. However, in non-growing animals the magnetic appliances caused less marked intrusion of the buccal teeth; no such changes were evident in the control animals. There was also no apparent maxillary skeletal displacement or mandibular remodelling in any of the animals.

In a similar animal study, Melsen *et al.* (1991) focused on the root formation of the unerupted teeth in the presence of magnetic and non-magnetic bite blocks. The findings showed more roots with an inverted Hertwig root sheath

in both groups, although this effect was more pronounced in the magnetic bite block group.

Comparative clinical studies with magnetic and acrylic posterior bite blocks have demonstrated that the therapeutic effect of magnetic bite blocks is characterized by anterior mandibular rotation, significant intrusion of the posterior teeth and open bite closure associated with maxillary incisor eruption and lingual tipping, these effects being especially marked in younger patients (Kiliaridis *et al.*, 1990; Barbre and Sinclair, 1991; Breunig and Rakosi, 1992; Kuster and Ingervall, 1992; Moss *et al.*, 1993). However, transverse problems (i.e. unilateral crossbite) due to lateral forces from repelling magnets and the potential for relapse in the long-term were also reported (Kiliaridis *et al.*, 1990; Kuster and Ingervall, 1992).

The MAD IV, designed in 1989 for the correction of open bites, acts with not only posterior repulsive magnets but also anterior attractive magnets, thus having the advantage of guiding the mandible to a midline centric position. These anterior magnets add an anterior closing effect, and accentuate and facilitate the anterior rotation of the mandible. Three types of MAD IV have been described for different open bite cases: MAD IV-a is used in cases where posterior intrusion and mandibular autorotation are required, i.e. gummy smile cases; MAD IV-b is used when an additional extrusive effect on the anterior part of the maxilla is necessary; and MAD IV-c is used if the only effect required is extrusion of the anterior area of the maxilla. All three patients treated with MAD IV resulted in an open bite anterior. Additional consequences included a slight increase in the inclination of both maxillary and mandibular incisors, a reduction in the mandibular plane angle and sagittal growth modification as reflected by a decrease in the ANB angle, which were different from the findings of other studies (Darendeliler *et al.*, 1995b).

Discussion and conclusion

The currently available literature evaluating magnetic fields shows no evidence of any direct or acute toxic effects. With the exception of a few

investigations conducted in humans, all of the experimental studies of biological implications reviewed in this article were designed to evaluate effects of static magnetic fields under laboratory conditions. In general, the biological effects reported in the majority of these studies have not revealed any pathological effects or any significant influences on cells or organ structure. There have also been reports of adverse effects such as stimulated bone resorption and a reduction in the number of epithelial cells, but this was by using acrylic-coated magnets (Linder-Aronson *et al.*, 1992). However, Vardimon and Mueller (1985) have already stated that acrylic alone was not an adequate coating material. It should also be noted that most of the studies reported have involved short-term exposure and thus normal biological variations may have masked any differences between exposed and unexposed subjects. It is also very important to recognize that none of these studies has been independently reproduced in a second laboratory and some have utilized unsatisfactory methodology or insufficient sample size (Blechman, 1991; De Vincenzo, 1991). Furthermore, the effects of static magnetic fields may be revealed at the atomic and molecular level, primarily via their biologically important ions such as calcium and magnesium. Thus, work currently in progress should concentrate on improving our limited understanding of biological interactions with static magnetic fields, particularly regarding their long-term nature.

Magnets tend to be oxidized in the oral environment and, due to the potential formation of corrosive products, the magnetic properties are likely to deteriorate. This disadvantage can be overcome by coating magnets. In addition, the magnetic force between two magnets markedly increases in attraction and decreases in repulsion, showing a negative correlation with the square of the distance. Contrary to attractive magnets, three-dimensional control using repelling magnets is therefore very difficult to achieve and requires auxiliary sliding mechanisms.

The use of rare earth permanent magnets in orthodontic and orthopaedic treatment has also

being described in the literature. At present, the most promising clinical uses for these magnets are mainly confined to tooth movement for impacted teeth and Class II and III malocclusions, as well as for the treatment of open bite cases. Despite the fact that the majority of studies are based on case reports, it can be concluded that, when compared with traditional techniques, magnets have some advantages, such as frictionless mechanics in attractive configuration, a predictable force level, and no loss of force due to relaxation of the atomic and crystallographic make-up of the material, as seen with arch wires.

Data obtained from clinical work conducted at the University of Geneva and from other published studies indicates that the use of magnets for orthodontic tooth movement is currently rather limited. Magnets remain too bulky and hard to manufacture for required designs to be used as full arch appliance systems for routine tooth movement applications. This approach has been tried in one patient and, although the chairtime was minimal and patient cooperation was not necessary except for maintaining good oral hygiene, we do not believe that it has any great advantage over conventional appliances (Darendeliler and Joho, 1992). Similar tooth movement rates can probably be obtained using superelastic coils, which are less bulky and demand less care.

Intra-arch repelling magnetic systems are commercially available and used clinically for research applications, especially in molar distalization. When the effects of static magnetic fields are taken into consideration, this technique was found less effective than conventional push-coil mechanics (Bondemark *et al.*, 1994b). However, the decrease in force in relation to the distance of separation is more important when using magnets in comparison with push-coils. In a study conducted in animals, repelling SmCo magnets produced more rapid tooth movement than orthodontic coil springs (Darendeliler *et al.*, 1995a). The reason underlying these two contradictory results might involve the different densities of magnetic fields, which may, in turn, influence different cell populations (Bassett, 1982).

Despite inadequacies in other clinical applications, magnets have obvious advantages for the guided eruption of impacted teeth, such as reduced irritation on the palatal mucosa, more control over force application and less requirement for patient cooperation. These factors are probably the main positive features of this alternative treatment approach.

The clinical use of magnets for maxillary expansion does not seem, at least at present, to have any advantages over traditional force systems. The only positive conclusion that can be drawn, even though indirectly, is that dental and skeletal expansion could be achieved in humans even with light continuous forces. A further potential positive factor which must be seriously considered when using light forces is the decreased risk of external root resorption.

Class II correction by growth modification is the most promising application for the use of magnets. Since 1986 a considerable number of Class II patients have been treated with MAD II at the University of Geneva. The use of the magnetically active MAD II appliance represents a truly functional approach where the patient's mandible is gently and progressively guided to a more harmonious anterior position.

As yet, the number of Class III patients treated with MAD III and the long-term results of such treatment are insufficient to reach any firm conclusions. However, taking into consideration Class III corrections and easy patient co-operation, the use of this type of appliance appears to be very promising.

After the first encouraging use of repelling magnets for open bite correction by Dellinger (1986), animal and clinical studies have revealed different results. Although open bite corrections have been obtained, problems included excessive posterior thickness and absence of mandibular guidance. In order to avoid these difficulties, anterior attractive and posterior repelling force combinations with smaller and thinner magnets have been used at the Universities of Geneva, Switzerland and Gazi, Ankara, Turkey in order to improve MAD IV for open bite malocclusions. Our clinical experience has revealed a rapid correction of open bites but long-term stability should be evaluated.

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