# CHAPTER II
# LITERATURE REVIEW

Research on magnets and magnetic materials has been progressed greatly in the last 25 years. Intensive efforts have been made to develop a magnetic material, of minimal size, that would generate sufficient force to move teeth. Magnetic force as a viable alternative to functional force system used in orthodontics was demonstrated in an animal study reported by Blechman and Smiley in 1978. The animal study using aluminium–nikel-cobalt (AlNiCo) magnets as the source of corrective force demonstrated the feasibility of this new technology. Their results suggested the biologic safety and mechanical efficacy of permanent magnets for orthodontics appliances.

The following literature review will be divided into five parts as follows:

I. The magnetic materials
II. The extent and flux density of static magnetic fields
III. The magnetic force generated by the magnet
IV. The force / flux relationships
V. The biological effect of the magnet

## I. The magnetic materials

Magnets were commonly categorized as "soft" and "hard" magnets. A hard magnet attracts other magnetic materials to it. It retains obvious magnetism more or less permanently. A soft magnet has obvious magnetism only when it was in a magnetic field. It is not permanently magnetized. If one plots these different characteristics on a graph in which the imposed magnetic field (H) from the horizontal axis and the total magnetization (M) from the vertical axis, one obtains a characteristic curve, resembling a thick S, known as a hysteresis loop (Figure 2.1).

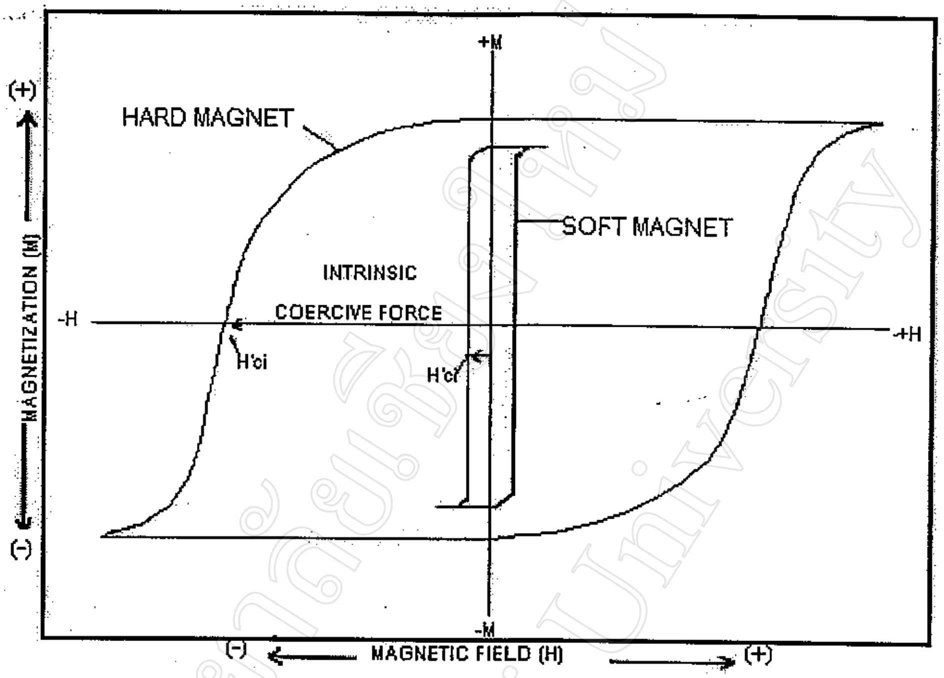

Figure 2.1 Hysteresis loop of soft and hard magnetic materials (Becker, 1970)

Hysteresis loop characterized the behavior of all magnetic materials when their magnetization (M) was measured as function of an imposed magnetic field (H). A hard magnet strongly resisted a change in the direction of its magnetization. Thus in a hard magnetic material the value of magnetization cannot be driven to zero until the imposed filed H reaches a substantial value; then M rises steeply. When the field is turned off, M remains high; the material remains magnetized. To return M to zero the direction or polarity of the imposed field must be reversed. The value of the field that returns M to zero is the intrinsic coercive force ($H'_{ci}$). If the strength of the field is still further, the material will finally become fully magnetized with the opposite polarity, and again it will remain magnetized when the field is removed. A soft magnets had low intrinsic coercive force, its weakly resisted a change in the direction of magnetization. A hard material has a wide hyteresis loop; a soft material has a thin one (Becker, 1970).

## Permanent magnet materials

A permanent magnet is a passive device used for generating a magnetic field. It dose not need and electric current flowing in a coil or solenoid to maintain the field. The energy needed to maintain the magnetic field has been stored previously when the permanent magnet was charged. There were various different magnetic materials which had been used as permanent magnets.

1. Magnetite or Lodestone – The material $Fe_3O_4$ which is a naturally occurring oxide of iron. It is the first permanent magnet material to be recognized.

2. Permanent magnet steels – The first commercially produced permanent magnets were high carbon steel containing about 1% carbon. Later permanent magnet steels were added of tungsten and chromium which improved the coercivity compare with the carbon steels. Later still came the cobalt steels. In these materials the improved magnetic properties arose from the presence of two second–phase particles, there by leading to higher coercivity and maximum energy product.

3. Alnico alloys - They consisted mainly of iron, cobalt, nickel, aluminum with small amounts of other metals such as copper. These constituents formed a finely intermixed two phase alloys consisting of a strongly magnetic phase (Fe-Co) and a very weakly magnetic phase (Ni-Al). These alloys were very hard and brittle; therefore, they could only be shaped by casting or by pressing and sintering of metal powder.

4. Hard ferrite – These materials, also known as ceramic magnets with the general composition of $(RFe_2O_4)_8$ when the indicated iron is $Fe^{3+}$, and R may be $Fe^{2+}$, $Ni^{2+}$, $Co^{2+}$, $Mn^{2+}$, $Zn^{2++}$. The hard hexagonal ferrite in wide spread use were usually either barium or strontium ferrite ($BaO.6\ Fe_2O_3$ or $SrO.6\ Fe_2O_3$).

5. Platinum–cobalt – This permanent magnet material was developed in the late 1950s. They were consisted of Pt and Co. Its magnetic properties were superior to other materials that were available at the time.

6. Samarium–cobalt - Samarium–cobalt permanent magnet based on alloys of the rare earth. The first of these alloys to be developed was $SmCo_5$ based on single phase. They had intrinsic coercive force 30 times and the maximum energy products

were about 3 times higher than the forces found in typical Alnico alloys. $Sm_2(Co, Cu)_{17}$ was base on precipitation–hardended alloys. They were partial substitution for Co by Cu in $SmCo_5$ could lead to high coercivity.

7. Neodymium-iron-boron - Neodymium–iron materials have large coercivities, but the properties of this alloys were not sufficiently reproducible. The addition of a small amount of boron was found to improve the properties dramatically. The main alloys contained $Nd_2Fe_{14}B$ phase. In general neodymium–iron-boron has rather poor temperature stability of it magnetic properties and poor corrosion resistance. The addition of small amount of copper and cobalt to the main $Nd_2Fe_{14}B$ composition was found to improve both coercivity and corrosion resistance without significantly reducing the remanence.

8. Nanostructured neodymium–iron–boron - This material was consisted of 90% soft phase (such as $\alpha$ Fe) and only 10% hard phase (such as $Nd_2Fe_{14}B$). Nanostructured neodymium–iron–boron alloys were prospect of high-performance, low–cost permanent magnet because $\alpha$ Fe was of course much cheaper than $Nd_2Fe_{14}B$.

9. Samarium–iron–nitride – The rare earth transition metal compounds of general composition $R_2T_{17}$, where R is a rare earth and T is a 3d transition metal. There were chemically more stable than other material with good corrosion resistance. Samarium–iron–nitride compounds also have in general the highest saturation magnetization values among the families of rare earth transition metal compounds.

There were different magnetic properties among various permanent magnetic materials such as coercivity, remanence and energy product. The magnetic properties of various permanent magnet materials were shown in Table 2.1.

Table 2.1The magnetic properties of various permanent magnet materials (David, 1998)

| Material | Composition | Remanence | Coercivity kA $m^{-1}$ | (BH)max kJ $m^{-3}$ |
|---|---|---|---|---|
| Steel | 99%Fe 1%C | 0.9 | 4 | 1.59 |
| 36Co Steel | 36%Co 3.75%W<br>5.75%Cr 0.8%C | 0.96 | 18.25 | 7.42 |
| Alnico2 | 12%Al 26%Ni<br>3%Cu 63%Fe | 0.7 | 52 | 13.5 |
| Alnico5 | 8%Al 15%Ni<br>3%Cu 50%Fe<br>24%Co | 1.2 | 57.6 | 40 |
| Ba ferrite | $BaO.6Fe_2O_3$ | 0.395 | 192 | 28 |
| PtCo | 77%Pt 23%Co | 0.645 | 344 | 76 |
| Samarium- cobalt | $SmCO_5$ | 0.9 | 696 | 160 |
| Neodymium-iron-boron | $Nd_2 Fe_{14}B$ | 1.3 | 1120 | 320 |

## II. The extent and flux density of static magnetic fields

Static kind of magnetic field has been schematically reproduced and characterized by " line". In the case of bar magnet, with the north pole at one end and the south pole at the other, the flux lines start from the north pole and follow a smaller or wider curve path return to the magnet at the south pole (Bondemark *et al.*, 1995) (Figure 2.2).

The magnetic field induced changes in the medium surrounding the magnet such as air. This was called the flux density of the magnet and could be measured by Hall probe. The flux produced by the magnets could attract or repel other magnets and could attract other materials containing iron (Noar and Evans,1999).

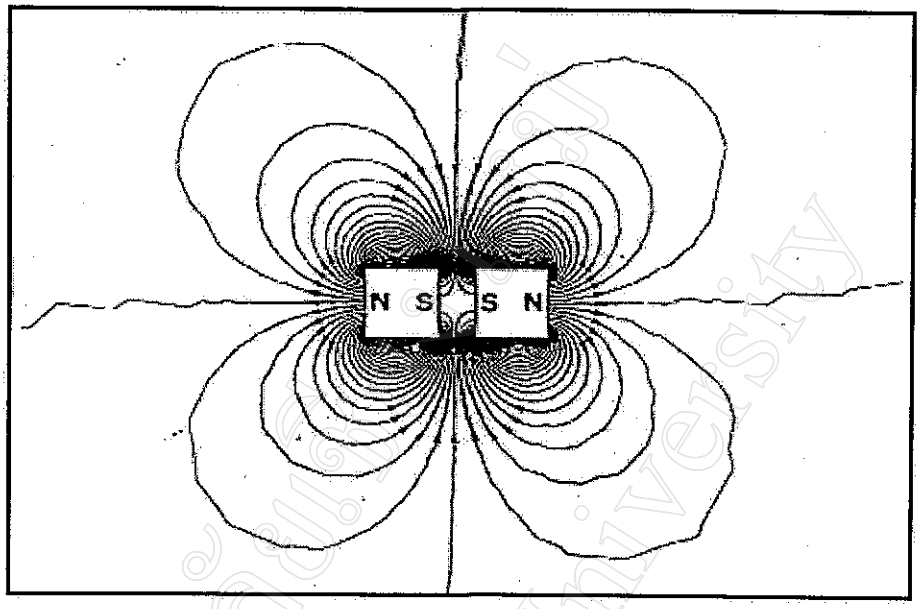

Figure 2.2 The magnetic filed of repelling magnets. N is north pole and S is south pole. (Bondemark *et al.*, 1995)

Bondemark *et al.* (1995) measured the extent and flux density of static magnetic field generated by samarium–cobalt ($Sm_2Co_{17}$). The flux density was measured with a gaussmeter and a Hall probe with the magnets mounted in attractive, repelling and single position. They found that the magnetic field generated by samarium–cobalt magnets were inhomogenous and the maximum flux density generated out from the pole faces. In the pole face contact, the magnets in attractive positions produced the highest flux density, followed by the single magnet and the repelling magnets. The magnetic field surrounding this magnet had a limited extent and the flux density decreased rapidly in all directions with increased distance from the magnets.

Noar *et al.* (1996a) investigated the magnetic flux of neodymium–iron–boron ($Nd_2Fe_{14}B$) which three different grades of magnets (Neo1i, Neo3i, Neo5i). The samples were supplied in five various sizes. The dimension of the magnets are 25x4.0x2.0 mm., 25x4.0x1.5 mm., 25x4.0x1.0 mm., 25x4.0x0.5 mm. And 5.0x5.0x1.5 mm. They found that the flux produced by the different thick sample which three different grades of magnets conformed similarly to the expected relationship between force and distance. The flux (F) produced by any two magnets was inversely proportional to the square of the distance (d) between them $F \propto 1/d^2$ (Figure 2.3).

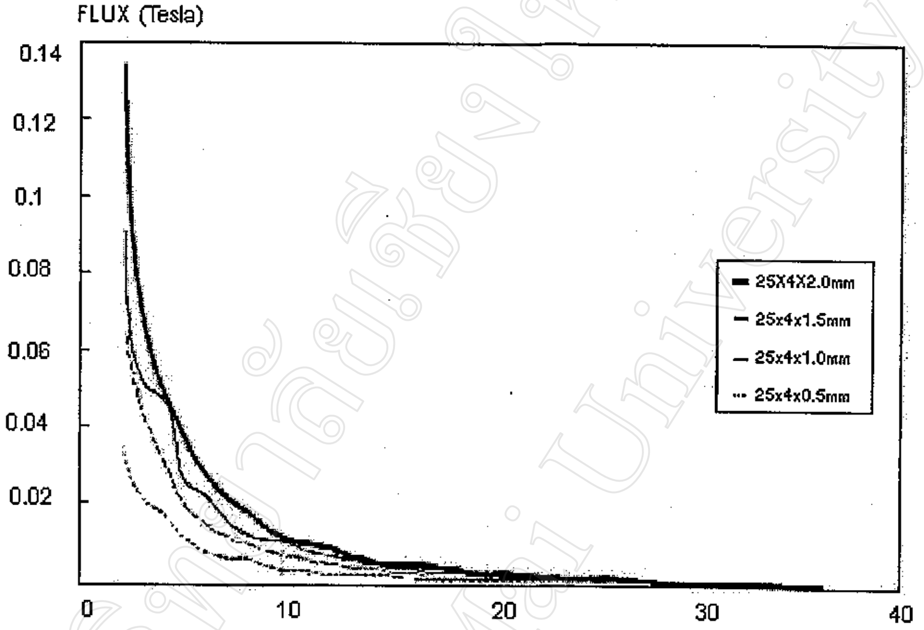

Figure 2.3 Flux comparisons of different thickness of magnets (Noar, Shell and Hunt 1996a)

There were significant differences in flux between the four dimensions and there was a linear relationship between thickness and flux. It was therefore possible to calculate the flux of one magnet of the same grade from the value of another. It was shown that at short distances from the magnets, the flux density at the ends of the magnets were on average, 31% less flux than the middle.

## III. The magnetic forces generated by magnets

### A. Factor influencing the magnetic forces

Many factors such as type of the magnets, size and shape, space between the magnets, position, and temperature affected the magnetic forces generated.

a) Type of the magnets

In the past, there were many types of magnets such as AlNiCo, Pt-Co, Ferrite have been used for various medical and dental application. However, these magnets had their limitations, particularly in relation to their size, cost and risk of demagnetization.

Recently, the rare earth magnets Samarium-cobalt had been developed. The introduction of samarium-cobalt magnet by Becker (1970) who used an alloy of cobalt and a rare earth metal samarium (SmCo), has helped to overcome these limitations.

Becker (1970) and Chin (1980) remarked that, when fully magnetized, a samarium-cobalt magnet had a ten–fold stronger magnetic field, and that its resistance to demagnetization was 20 to 50 times superior to the AlNiCo type of magnets. Tsutsui *et al.* (1979) studied the magnetic properties of Sm-Co, $AlNiCo_5$, Pt-Co, $AlNiCo_8$ and ferrite. They found that the magnetic force of the Sm-Co magnet was twice as large as that of $AlNiCo_5$, Pt-Co, $AlNiCo_8$ and ferrite.

Another type of magnet is the neodymium-iron-boron ($Nd_2Fe_{14}B$) group had a higher energy product than $Sm_2Co_{17}$ magnets, but had less resistance to demagnetization, and was more prone to corrosion. Robinson (1984) reported that the neodymium-iron-boron ($Nd_2Fe_{14}B$) had energy product of 290 kJ/$m^3$, Higher than $Sm_2Co_{17}$ magnets. Vardimon *et al.* (1989) investigated the force and distance relationship for vertical displaced pairs of samarium cobalt ($SmCo_5$) and neodymium–iron–boron ($Nd_2Fe_{14}B$). They found that at 3.0 millimeters separation the neodymium–iron-boron exhibited forces greater by two-fold than the samarium-cobalt for the same rectangular size.

b) Size and shape of the magnets

Size and shape of the magnets effected the force generated by the magnet. The length of the magnetic axis and the extension of the pole surface were the factor influencing the magnetic force.

Vardimon *et al.* (1991) compared the magnetic force between square and cylinder shape in another size and volume. They found that, in the contact position of the magnets, maximum force of a long slender cylinder–shaped magnet was greater than that of a short wide disk-shaped magnet although a short wide disk-shaped magnet has greater volume than a long slender cylinder–shaped magnet. However, a long slender cylinder–shaped magnet exhibited a steeper force/distance curve than a short wide disk-shaped magnet. There was a rapid decline in force with increased distance in comparison to the disk-shaped. At a gap of 1.5 to 3.0 millimeters between the magnets, the disk-shaped magnet exerts an attractive force greater than the cylinder-shaped magnet (Figure 2.4).

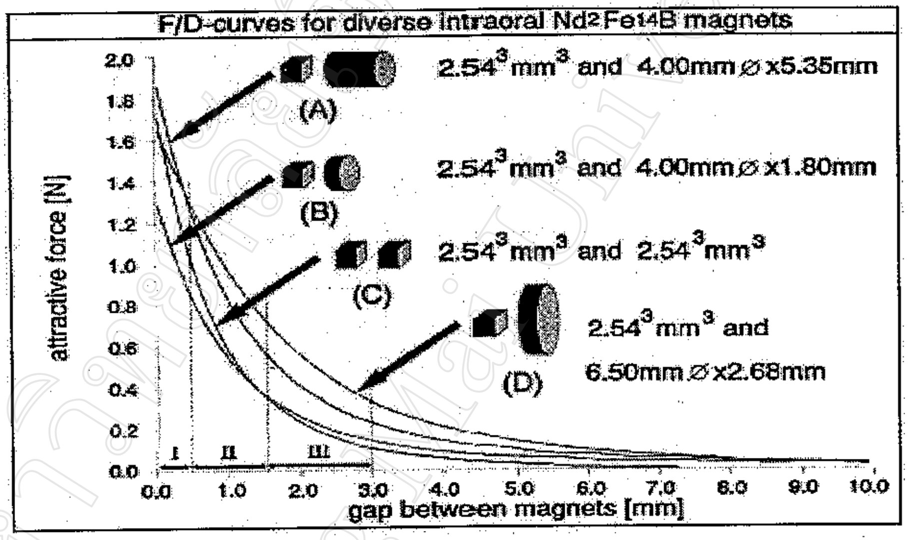

Figure 2.4 Change in force magnitude with respect to distance between magnets in difference magnets dimension (Vardimon *et al.* 1991)

In the vertical and transverse displacement positions, the wide disk–shaped magnet exerted attractive force greater than the long cylinder–shaped magnet. Therefore, the wide disk–shaped magnet exhibited a greater range of verticotransverse displacement from centric spatial orientation of the magnets than the long slender cylinder.

Mancini *et al.* (1999) supported the study of Vardimon *et al.* (1991) that the magnets with larger pole face areas and longer magnetic axes provided the higher attractive force.

Noar *et al.* (1996a) showed significant differences in forces between the different thickness. There was a linear relationship between the thickness of the magnets and the magnetic force. They found that groups of smaller magnets would produce better forces than one magnet of equivalent dimension, but the smaller magnets in combinations of N-N and S-S repulsion were found to be of no advantage because of the difficulties of alignment.

c) Force and distance relationship

Many investigators studied the force and distance relationship of the magnets. Vardimon (1987), Vardimon *et al.* (1989), Bondemark, Kurol and Jonkoping (1992) reported that the force and distance relationship for magnets that were vertically separated along a linear parallel to their magnetization axes was hyperbolic.

When the magnets were more than a few millimeters apart, the force produced between the magnets droped dramatically (Figure 2.5). The force increased inversely to the second power of the distance, Coulomb's law -$F \propto 1/d^2$(Noar *et al.*, 1996a; Mancini *et al.* 1999).

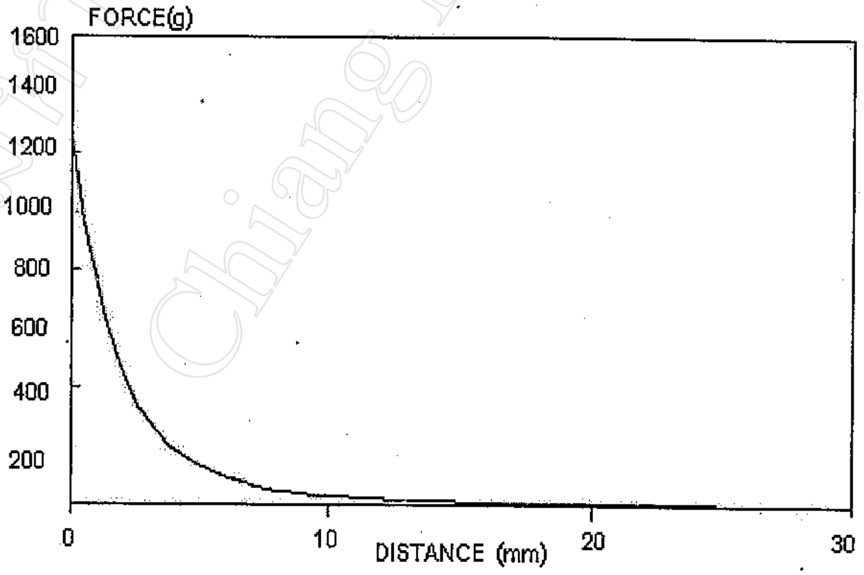

Figure 2.5 Force produced between two magnets (Noar *et al.* 1996a)

Daskalogiannakis and McLachlan (1996) indicated that when two magnets were in repulsion or attraction, their magnitude was roughly inversely proportional to square of air gap between two magnets (Coulomb's law). However, when three magnets were combined so that two poles in attraction and two in repulsion, there was certain range of activation for which force magnitude remains practically unchanged (Figure 2.6)

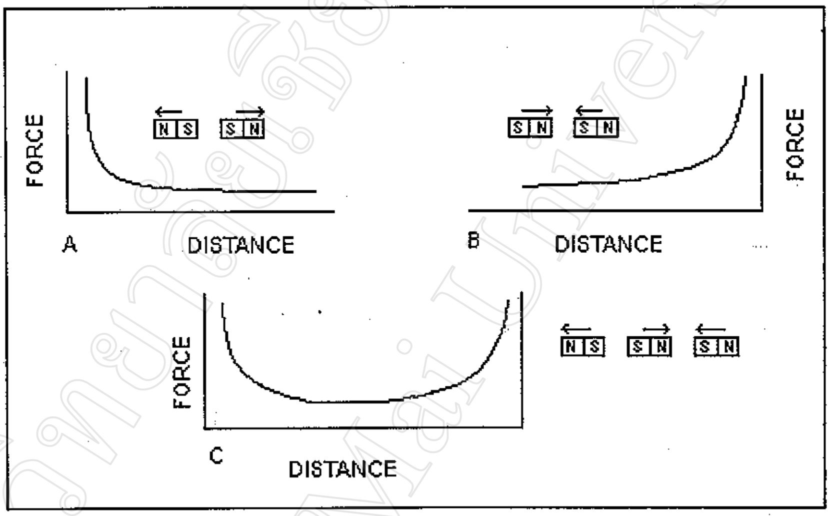

Figure 2.6 Force-distance curve. A–repelling position, B–attractive position, C–combined repelling and attractive position (Daskalogiannakis and McLachlan, 1996)

Fraunhofer, *et al.* (1992) investigated the forces generated by samarium–cobalt magnets in repulsion and attraction of two pair magnets. The results showed that samarium cobalt magnets had two district regions of behaviour. The force between the samarium cobalt magnets followed Coulomb's law of force only at separations equal to or more than 2.0 millimeters. At separations less than 2.0 millimeters, the force between the magnets was approximated to an inverse relationship with the square root of the distance between the magnets. Thus, the force between the magnets, in both attraction and repulsion, was decreased at small separations by an order of magnitude. In contrast, at larger separations when Coulomb's law was followed, there was a much smaller change in magnetic force with changes in magnet separation.

d) Position of the magnets

The position of the magnets was upmost importance. The magnetic force and flux density decreased with increasing vertical, transverse and horizontal separation.

Noar *et al.* (1996b) investigated the magnetic flux and repulsive force of neodymium-iron-boron magnets in different orientations; perfect alignment, tilted alignment, skewed alignment and edge to edge alignment. The result showed that there were strong statistical differences of repulsive force between them. If the magnets were a few millimeters apart, tilted at a relative angle of 13 $^0$ or skewed at a relative angle of $9^0$ and edge to edge alignment, the force produced between the magnets drops dramatically.

Mancini *et al.* (1999) investigated the effect of the pole face angles of the magnets to the attractive force and flux density of neodymium-iron-boron magnets. The result showed that the pole face angles of the magnets were effected to reduce the attractive force and flux density of them. The rate of decline of force and flex density was more rapid when the base magnet was posterior offset and the superior magnet angle was greater than 0 degree. The explanation of these finding was that off set and angulation of the magnet reduced pole face overlap directly, affecting the magnetic flux density, direction and force of attraction.

e) Temperature

The magnetic properties can be destroyed if the magnet is exposed to a temperature close to or exceeding the Curies temperature. The magnets tend to lose their properties if sujected to a specific temperature, wich causes their domains to return to random distribution. This is called the Curie point. AlNiCo has a high Curies point to permit thermal reconditioning, but rare earth magnets have low Curie point. However, by combining with other elements, this temperature-specific magnetism can be overcome. The combining elements is not necessary to be metals (i.e.,boron). Neodymium-iron-boron magnet thus can withstand $100^0$C for 4,000 hours without losing its potency (Graber, 1997).

The Cuies temperature for samarium cobalt magnets is 680$^0$C. The temperature up to which magnetic properties do not deteriorate is 200$^0$C. Therefore, the magnet can be treated with boiling water (Tsutsui *et al.*1979).

Bondemark *et al.* (1992) indicated that the force magnitude of the samarium cobalt magnets was decreased by 3.5% (range 0–3.5 %) after clinical use and sterilization in an autoclave.

Noar *et al.* (1996b) investigated the magnetic flux of neodymium–iron–boron ($Nd_2Fe_{14}B$) with acrylic coatings. The results showed that there was no magnetic loss after coating the magnets as a result of the increased temperatures of 80$^0$C owing to the epoxy resin cure around the magnet. However, Neo1i (19.5 %) and Neo5i (16.4 %) showed loss of flux after being heated to 88 $^0$C.

B. Force/flux relationships

The relationship between force and flux density was important from a clinical perspective, as a flux density measurement taken at the chairside would help the clinician to predict the magnetic force.

Noar *et al.* (1996a) found the relationship between the force and flux of the neodymium–iron–boron. The repulsive force between two magnets could be calculated by measuring the flux above one magnet.

Mancini *et al.* (1999) investigated the force and flux relationship of the nine sets neodymium–iron–boron magnet pairs with the difference morphologies. Each pairs magnets were separated vertically, and no offset or superior magnet angulation. They found that the correlation of force and flux was nearly 100 per cent in all nine cases, but the clinical relevance of their relationships was debatable. The clinician was uncertain as to the orientation of the bonded magnet as it was highly unlikely that the pairs have been ideally spatially related. Some cares must be exercised when attempting to predict the force levels; therefore, the relationship should be used as a guide only.

## IV. The biological effect of magnet

The biocompatibility of orthodontic magnet, the nature of the surrounding static magnetic fields and the possible risk of harmful or unusual reactions in tissues and cells exposed to weak static magnetic fields have attracted interest and have also been debated. Biological safety testing of magnets have been evaluated the effects of both the static magnetic field and possible toxic of materials of their corrosion. Several studies have shown the magnets have good biocompatibility. One of the studies of the AlNiCo was reported by Blechman and Smiley (1978). They did not find any abnormalities produced by magnetic field which examining the samples taken from adjacent tissues after nine month experimental period.

Tsutsui *et al.* (1979) 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 effect on the tissues and could be used dental material if plated or coated.

Sandler *et al.* (1989) investigated short–term biological effects of neodymium-iron-boron magnets. They found neodymium-iron-boron magnets had no cytotoxic effect on osteoblast-like cells (UMR-106). Altay *et al.* (1991) reported no abnormal healing or osteoblastic activity and no osteoblastic activity and no notable difference in cell size, shape or content after implantation of titanium-coated SmCo magnets in dog mandibles for a period of six months.

Bondemark *et al.* (1994a,b) evaluated the biological effect of the corrosion product of neodymium-iron-boron magnets in three different states; new, after clinical use and recycle. The cytotoxic effect was highest with the new magnets, less marked with the clinically used ones and smallest with the recycled magnets. The out come of these studies demonstrated a range of effects from no cytotoxic effects to mild cytotoxic effects.

Bondemark *et al.* (1995) reported that static magnetic fields produced by orally placed orthodontic rare earth magnets did not cause any change in human dental pulp or gingival tissue adjacent to the magnets. Bondemark *et al.* (1998) examined human buccal mucosa clinically, histologically and immunohisto-chemically after nine months exposure to neodymium–iron-boron orthodontic magnets. They found that no adverse long–term effects on human buccal mucosa which had been in contact with an acrylic coated neodymium–iron-boron magnets.

On the other hand, some studies have reported changes in cell morphology and in cell metabolism after exposure to weak static magnetic field. Rare earth magnets, which are most commonly used in orthodontic corroded easily. Vardimon and Muller (1985) suggested that rare earth magnets and those containing neodymium were susceptible to corrosion with the release of potentially harmful product.

Linder–Aronson and Lindskog (1991) showed that permanent $SmCo_5$ magnet applied in close contract with the rat hind leg resulted in increased bone resorption of the tibia and a thinner epithelium after 4 weeks. Linder–Aronson *et al.* (1992) reported that the magnetic field or corrosion products from the magnetic material influenced vita processes in the epithelium and the bone close to the magnet.

Linder–Aronson *et al.* (1995) confirmed previous results on the effect of rare earth permanent magnets that exposure of the proximal tibia of young rats to $SmCo_5$ magnets resulted thinner epithelium and retarded rate of bone formation .

Linder–Aronson and Lindskog (1995) observed when human periodontal fibroblasts were cultured in a static magnetic field. They concluded that a static magnetic field itself was capable of influencing vital cell functions.

## V. Clinical application of magnets

Magnets have been used in dentistry for many years most commonly to aid the retention of denture and overdenture (Javid, 1971, Gilling, 1981). In orthodontic they have been used in clinical practice particularly in tooth movement, treatment of unerupted teeth, correction of anterior openbite, functional appliance, expansion and fixed retention.

Magnets have also been employed in different ways to achieve space closure. In a preliminary study, Muller (1984) used rectangular magnets applying light attracting continuous force for median diastema closure without archwire. The author noted that the magnets produce a light continuous force.

Blechman (1985) reported the successful of SmCo magnets in combination with edgewise device for the application of intra-maxillary and inter-maxillary forces. It was suggested that the magnets can be used in attraction or repulsion to move the teeth along archwires, provide Class II traction and to intrude/extrude individual teeth. Double tube were used on the molars and the magnets mounted on sectional archwire. A base full arch was used to control the direction of the tooth movement.

Kawata *et al.* (1987) introduced a new force system of magnetised edgewise brackets. The magnetic brackets were chromium-plated samarium-cobalt magnets soldered to the base of an edgewise bracket which were directly bonded to the teeth and were designed to from an ideal arch shape in the maxilla and mandible at the completion of treatment. Force levels delivered to the teeth were estimated at 250 grams. Bracket placement allowed mesial and distal movement of teeth only if the inter-bracket distance was less than 3.0 mm.

Bondemark and Kurol (1992) discussed the simultaneous movement of first and second molars using repelling samarium-cobalt magnets. Repelling force levels of 58-215 grams were used and all of maxillary molars were moved to Class I relationship within 16.6 weeks. Molar distalization was mainly due to distal tipping and rotation movement with no statistical significant skeletal changes.

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 subgingivally fractured incisor by means of SmCo magnets, one fixed to the root and one embedded in removable partial denture. The guided eruption of an impacted canine was first reported by Sandler *et al.*(1989). The technique were surgical exposure of an impacted tooth, a magnet was bonded to the tooth surface and the mucosal flap was suture in place, completely covering the tooth with its bonded magnet. Guided eruption was achieved by means of second intraoral magnet embedded in a removable plate and placed in such a way as to attract the submucosal magnet. Vardimon *et al.*

(1991) have described different magnetic arrangement which utilize a vertical magnetic bracket for impacted incisors and canine, a horizontal magnetic bracket for impacted premolar and molars. The author concluded that the use of magnets was effective for the eruption and impacted teeth, that treatment time and discomfort were reduced, and that no side effect was observed.

Dellinger (1986) introduced the active vertical corrector (AVC) used to correct anterior open bite. This appliance used samarium cobalt magnets, orientated in repulsion producing a posterior intrusive force of 600-700 grams per magnetic unit. The author reported that the four cases treated with this appliance showed little tendency toward re-eruption of the molars, but some labial or lingual tipping of the maxillary incisors was observed. Comparative clinical studies with magnetic and acrylic posterior bite blocks have demonstrated that the therapeutic effect of magnetic bite blocks was characterized by anterior mandibular rotation, significant intrusion of the posterior teeth and open bite closure associated with maxillary posterior and lingual tipping. These effects were especially marked in younger patients. However, transverse problems due to lateral forces from repelling magnets and the potential for relapse in the long term were reported (Kiliaridis *et al.*1990, Barbre and sinclair 1991, Kuster and Ingervall 1992).

Magnets have been used for the correction of Class II and Class III malocclusion. Vardimon *et al.*(1989,1990) developed the functional orthopaedic device (FOMA II and FOMA III), which has shown positive treatment effects in monkeys. In the case of FOMA II upper and lower attracting neodymium-iron-boron magnets maintain the mandible in an advanced sagittal position. Kalra *et al.* (1989) reported the use of 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, they reported a significant increase in the length of the mandible, and a decrease of mandibular angle in childen receiving active treatment.

A FOMA III appliance with two neodymium-iron-boron magnets in a centripetal attractive force configuration exerting both vertical and horizontal force factors in anterior region was designed by Vardimon *et al.*(1990) for the treatment of Class III malocclusion. Six monkeys received sham appliances. Over 4 month period, despite on cephalometric changes at the cranial base level, a marked effect was seen in the midfacial complex with a significant forward movement of maxillary incisors and fist molars. Clinical applications for the magnetic activator device (MAD) III appliance have been reported by Darendelier *et al.*(1993). This activator consisted 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 was pulled distally and the maxilla mesially.

Repulsive magnetic forces for intra-maxillary expansion and orthopaedic movement of the palatal shelves were first described by Vardimon *et al.*(1987). They reported on a study that looked into the effected of using samarium-cobalt magnets to provide the expansion force on monkeys. This study demonstrated that magnetic expansion produced control forces over a predicted range of time. The expansion was slow compared with rapid maxillary expansion technique and there was less tendency for the mid-palatal suture to fracture.

The use of magnets has also been reported to retained teeth. For example, in a case report by Springate and Sandler (1992), small, thin neodymium-iron-boron magnets were bonded onto the palatal surface of the upper incisors in order to prevent re-opening of a dyastema.