CHAPTER V
DISCUSSION

The discussion was presented as follows;

Part I : The magnetic force generated by orthodontic and commercial magnets.

1.1 The comparison of mean of magnetic force generated by the commercial and orthodontic magnets.

1.2 The correlations between magnetic forces and size of commercial magnets.

Part II : The composition and crystal structure of the commercial and orthodontic magnets.

Part I : The magnetic force generated by orthodontic and commercial magnets.

This study has shown that the force-distance curves of orthodontic and commercial magnets were slightly different. The force–distance curve of orthodontic and commercial magnets was hyperbolic (Figure 4.1). At initial position, the mean of magnetic force attracting to orthodontic bracket was greatest. When the distance between the magnet and orthodontic bracket were more than a few millimeters a part, the mean of magnetic force dropped dramatically. The mean of magnetic force increased approximately inversely to the second power of the distance which was characteristic of Coulomb's law ($F \propto 1/d^2$) accordance with the finding of previous studies by Vardimon (1987), Vardimon *et al* (1989), Bondemark, Kurol and Jonkoping (1992), Noar *et al.*(1996), Mancini *et al.* (1999).

From Table 2, at initial, the mean of magnetic force of group 2 (commercial magnets 3.28x3.28x2.0 mm.) was greatest and the sequence of the mean of magnetic force following from maximum to minimum were group 2 (commercial magnets 3.28x3.28x2.0 mm.), group 1 (orthodontic magnets 3.7mm.ϕx2.0 mm.), group 3 (commercial magnets 6.0x6.0x2.0mm.), group 4 (commercial magnets 8.0x8.0x2.0 mm.) and group 5 (commercial magnets 10.0x10.0x2.0 mm.). However, at distances 0.5, 1.0, 1.5 millimeters, the mean of magnetic force of group 3 (commercial magnets 6.0x6.0x2.0 mm.) was greater than group 2 (commercial magnets 3.28x3.28x2.0 mm.) and group 1 (orthodontic magnets 3.7mm.ϕx2.0 mm.) because at distances; initial, 0.25, 0.5, 1.0, 1.5 millimeters, orthodontic magnets (3.7 mm.ϕx2.0 mm.) and commercial magnets (3.28x3.28x2.0 mm.) exhibited a steeper force–distance curve than commercial magnets (6.0x6.0x2.0 mm., 8.0x8.0x2.0 mm., 10.0x10.0x2.0 mm.). It was shown that at distances; initial, 0.25, 0.5, 1.0, 1.5 millimeters, when the distance increased the mean of magnetic forces of orthodontic magnet (3.7mm.ϕx2.0 mm.) and commercial magnet (3.28x3.28x2.0 mm.) dropped greater than commercial magnets (6.0x6.0x2.0 mm., 8.0x8.0x2.0 mm., 10.0x10.0x2.0 mm.).

According to Vardimon *et al.* (1991), they compared the magnetic force between square and cylinder shape in another size and volume. They found that, in the initial position of the magnets, maximum force of a long slender cylinder–shaped magnet was greater than that of a short wide disk-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).

At distances 2.0, 2.5, 3.0, 4.0, 5.0 millimeters the mean of magnetic forces of five groups showed slight difference. There were low magnetic force values because the magnetic force attracting to orthodontic bracket was upon the magnetic density.

The magnetic field generated by magnet was inhomogenous. The maximum flux density of single magnet generated out from the pole faces. The magnetic filed surrounding single magnet had a limited extent and the flux density decrease rapidly in all directions with increased distance (Bondemark *et al.*,1995). When the distances between the magnet and orthodontic bracket increased, flux density decreased rapidly.

1.1 The comparison of mean of magnetic force of the commercial and orthodontic magnets.

The commercial magnets (3.28x3.28x2.0 mm.) had relatively equal volume to the orthodontic magnets (3.7mm.ϕx2.0 mm.). Mean of magnetic force attracting to orthodontic bracket in various distances could be compared.

The mean of magnetic force of commercial magnets attracting to orthodontic bracket was greater than the mean of magnetic force of orthodontic magnets to orthodontic bracket in various distances. Table 4.1 showed a significant difference in the mean of magnetic force of orthodontic and commercial magnets at $p<0.001$, $p<0.01$, $p<0.05$. There were two factors that might affect the differences of the mean of magnetic force between commercial and orthodontic magnets.

The composition of the magnet was one factor. According to Noar *et al.* (1996a), they compared the magnetic flux of neodymium magnets in different grades; Neo1i, Neo3i and Neo5i. They found that the flux density of neodymium group which different grades was different. This implied that the magnetic forces of neodymium magnets in different grades; Neo1i, Neo3i and Neo5I were different. Vardimon et al. (1989) compared the magnetic force of pairs samarium cobalt ($SmCo_5$) and pairs neodymium-iron-boron ($Nd_2Fe_{14}B$). They found that pairs neodymium-iron-boron exhibited forces greater that pairs samarium cobalt for the same rectangular size.

Another factor that might affect differences of magnetic force between commercial and orthodontic magnets was the shape of magnet. The volume of commercial and orthodontic magnets used in this study were relatively equal but the shapes were different. The shape of commercial magnet was cubic but the shape of orthodontic magnet was cylinder. According to Vardimon *et al.* (1991), they reported that the magnetic force between two cubic shape (2.54^3 mm^3) magnets were greater than the magnetic force between cubic shape (2.54^3 mm^3) and cylinder shape (4.0mm. ϕx1.8 mm.) magnets. However, the volume of cylinder shape (4.0mm.ϕx1.8 mm.) magnet was greater than volume of cubic shape (2.54^3 mm^3) magnet.

The commercial magnets had greater standard deviation of magnetic force than orthodontic magnets (table 4.1). This showed that the difference in magnetic force between the individual commercial magnets were greater than orthodontic magnets.

The data from this study showed that the mean of magnetic force of the commercial magnets attracting to orthodontic bracket was greater than that of the orthodontic magnets which had the same volume. It might be applied to use the commercial magnets in clinical orthodontic treatment instead of orthodontic magnets.

However, the greatest of mean of magnetic force values of commercial magnet attracting to orthodontic bracket was 76.89 grams at contact position and decreased to 14.69, 7.44, 6.32 grams when the distance between magnet to orthodontic bracket increased to 1.0, 2.0,3.0 millimeters respectively. The magnetic force values were relatively less for being applied in clinical orthodontic treatment.

In contemporary orthodontics, light continuous forces (75 grams to 100 grams) were commonly used to correct malocclusion with typical tooth movement (0.5 millimeters/weeks). Blechman (1985) and Gianelly (1988) reported that for intramaxillary use in the movement of single tooth, the forces were vary, starting at about 225-285 grams and dropping to 75-164 grams with space between the magnets1.0 millimeters.

Darendeliler and Friedli (1994) reported the combined use of removable and fixed type attraction systems for and impacted upper canines 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 millimeters and was approximately 45 grams at 1.5 millimeters.

The method for increasing the attractive forces of this commercial magnet by used commercial magnet attracting to commercial magnet substitute orthodontic bracket or increased the thickness of the magnets. Bondemark et al. (1997) reported with axial arrangement of two small cylindrical neodymium-iron-boron magnet together

2 x (3.0mm.ϕx2.0mm.) and larger magnet (5.0x5.0x2.0 mm.) forces were somewhat higher than if one small magnet (3.0mm. ϕx2.0mm.) was used. In both systems, gap between magnet should not exceed 2.0 mm.. Vardimon *et al.* (1991) reported that the distance between the two poles of a magnet was the factor affect in the maximum attractive force. Increasing the interpole distance of the magnet was increased the maximum attractive force.

After the experiments it was found that the surface of the commercial magnets that had been cleaned previously for the force testing experiments had corroded. This did not occur in orthodontic magnets which being coated with a biocompatible polymer.

The rare earth magnets were known to be easily corroded so there might be a risk of negative biological effects of the corrosion products of the magnets and a risk of disturbed physical properties and tarnishing of the magnets after the corrosion assaults.

Vardimon and Muller (1985) suggested that rare earth magnets and, in particular, those containing neodymium were susceptible to corrosion with release of potentially harmful product.

Many methods were recommended to protect magnet from being corroded for example coating the magnet with biocompatible epoxy resin (Blechman,1985), stainless steel (Cerny, 1978) or a thin layer of parylene (Vardimon *et al.*,1991).

Blechman (1985) also addressed the biological safety of the magnets. The magnets were embedded in biocompatible epoxy resin to prevent corrosion products leaking into the tissues. Frequent physical examination by a paediatric consultant was performed and urinary cobalt studies were carried out every 6 months during treatment. No abnormal result was reported and it was concluded that no biological harzard exists.

1.2 The correlation between magnetic force and size of commercial magnets.

From table 4.3, it was found that, at distances; initial, 0.25, 0.5, 1.0 millimeters there was negative correlation between size of commercial magnets and magnetic force attracting to orthodontic bracket. It was shown that smaller sizes of commercial magnet exhibited higher magnetic force of magnet attracting to orthodontic bracket than bigger sizes.

However; at distances; 1.5, 2.0, 2.5, 3.0, 4.0, 5.0 millimeters there was no correlation between size of commercial magnets and magnetic force.

In this studies, the commercial magnets were not manufactured in their ideally sizes. Cutting and shaping procedure were necessary to prepare the sizes of commercial magnets from the piece of magnetized magnets. The pole face position of commercial magnets could not be assigned. The factor affecting the result of this studies might be the pole face position of the magnets. Bondemark *et al.* (1995) reported that the highest flux density was always generated out from the pole faces.

The pole faces position of these commercial magnets were not at the middle part but their position at the end of magnets. The distances between the orthodontic bracket and the pole face position affected to the value of the magnetic force attract to orthodontic bracket. The magnetic forces decreased exponentially with increased the distances between orthodontic bracket and the pole face position.

Conversely, Noar *et al.* (1999) studied the magnetic forces of neodymium-iron-boron magnets which manufactured in their ideally use size before magnetized. They found that the flux density at the end of the magnets were on average, 31% less flux than the middle at short distance, thus the face between magnets were at the end.

Part II : The composition and crystal structure of the commercial and orthodontic magnets.

The results from this study showed that the micrograph of each region of orthodontic and commercial magnets were a grain in the casting. The morphology of orthodontic magnet was heterogenous. The main surface of orthodontic magnet was the dark grains (black area) and substituted with some light grains (white area). The composition within each grain of orthodontic magnets were slightly different. The main composition in dark and light grains of orthodontic magnet was iron (Fe).

The orthodontic magnets used in this study were supplied from Ormco Company. The supplier indicated these magnets were samarium cobalt magnets. Although the supplier did not notify exact details of magnet composition, the data from EDX analysis showed the composition in dark and light grain of orthodontic magnets was iron (Fe), cobalt (Co), copper (Cu), neodymium (Nd) and gadolinium (Gd), but not samarium (Sm).

The morphology of commercial magnets grains was heterogenous. The surface of commercial magnet was combined with dark and light grains in different grain sizes and shapes. The composition within each grain of orthodontic magnets were quite different. The composition in dark and light grains of commercial magnet consisted of iron (Fe), cobalt (Co), neodymium (Nd), gadolinium (Gd). The main composition in dark and light grains of commercial magnet was neodymium (Nd) and iron (Fe). The component which has greatest intensity in dark grain of commercial magnet was iron (Fe) but the component which has greatest intensity in white light grain of commercial magnet was neodymium (Nd).

The crystal structure of orthodontic and commercial magnets were investigated by x-ray diffraction analysis. There could not be found the data of JCPDS file which has the series of d-spacing value equal the series of d-spacing value of orthodontic and commercial magnets. From analyzed data, the orthodontic and commercial magnets might be a compound which consisted of more than two phases. It disturbed the use of x-ray diffraction analysis because the x-ray diffractometer could not analyze the real structure if the sample has more than two phases.

The structure of the commercial magnets might be the neodymium-iron-boron groups which possibly in addition of other elements such as cobalt, gadolimium and copper. Combining elements might affect the structure of material, had more than two phases. The addition elements can obtain a satisfactory structure of these materials.

In general neodymium-iron-boron had rather poor temperature stability of its magnetic properties and poor corrosion resistance. The addition of small amounts of copper and cobalt to main neodymium-iron-boron composition was found to improve both coercivity and corrosion resistance without significantly reducing remanence (David, 1998). The gadolinium (Gd) addition was used to decrease the temperature coefficient of remanence, a useful in temperature stable devices (Chin, 1980).

LIMITATION OF THIS INVESTIGATION

1. The magnetic forces level of orthodontic and commercial magnets in this study were less than 10 newtons but load cell of the universal testing machine in magnetic force test were 100 newtons. It affected the sensitivity of the universal testing machine to detect the magnetic forces.

2. The commercial magnets were not manufactured in their ideally sizes from the supplier. It was necessary to cut and shape the magnets. The magnets might be demagnetized by heat during cutting and shaping procedure.

3. The pole face position of the commercial magnets could not be identified.

4. The shapes of commercial and orthodontic magnets were different. The shape of commercial magnets were cubic but the shape of orthodontic magnets were cylinder. This might affect to the difference of magnetic forces between commercial and orthodontic magnets.

SUGGESTIONS FOR FUTHER STUDY

1.The actually load cell of the universal testing machine in magnetic force test should be smaller than 100 newtons for better sensitivity.

2. Further research projects are recommended to investigate the attractive and repelling forces between commercial magnets in each sizes.

3. The water or oil cooling systems should be used during the cutting and shaping of commercial magnet procedures for resist demagnetization of magnets by heat during cutting and shaping procedures.

4. Before applying the commercial magnets in clinical orthodontic treatment, it is important to ensure that the commercial magnet should not produce any side-effect at a local and systemic level. The biocompatibility of this commercial magnets should be investigated.