Force generation by orthodontic samarium-cobalt magnets

J.A. von Fraunhofer, MSc, PhD; P.W. Bonds, DMD, MS; B.E. Johnson, DMD, MS

In contemporary orthodontics, light continuous forces (75g to 100g[1]) are commonly used to correct malocclusions with typical tooth movements of 0.5mm/wk. Miniature samarium-cobalt (Sm-Co) magnets have been advocated as an efficient, effective force delivery system.

Magnets have been used in dentistry for a variety of purposes, most commonly to aid in the retention of oral and maxillofacial prostheses. Ferrite, alnico (Al/Ni/Co) or platinum-cobalt magnets[2-3] have been used but, due to their low magnetic strength, they must be relatively large to be effective. The development of rare-earth magnets of high magnetic strength permitted a significant reduction in size. Samarium-cobalt magnets can provide forces within the optimum range, with tooth movement approaching 2mm/month.[4,5] However, there appears to be relatively little in the literature on the use of samarium-cobalt magnets in orthodontic treatment. This study was undertaken to characterize the forces generated by Sm-Co magnets when used for orthodontic tooth movement.

Materials and methods

Three sets of samarium-cobalt magnets (Medical Magnetics, Inc., Ramsey, New Jersey) were tested in repulsion and three sets were tested in attraction. Each set contained two pairs of magnets.

Two aluminum rods (15mm x 6.35mm dia) were mounted to the movable crosshead and to the base

Abstract

The use of samarium-cobalt (Sm-Co) magnets for light force application is a relatively new concept in orthodontic tooth movement. This study reports on the forces generated by these magnets.

Magnets were attached to aluminum rods mounted in a universal testing machine. The magnets were initially separated by 10mm and were moved toward each other at 2.5mm/min in repulsion or attraction, depending upon the magnetic pole orientation. The magnets were also positioned initially in contact and then moved apart at a rate of 2.5mm/min, again producing repulsion or attraction, depending upon the pole orientation.

The Sm-Co magnets exhibit very large forces when in close approximation but forces decrease markedly at separations greater than 2mm. The force, P, generated between magnets is determined by their separation, d, and follows the relationship $P=d^n$. At magnet separations of 0 to 2mm, the exponent n is equal to -0.4; at separations of 2mm to 7mm, exponent n equals -2.1 for both attraction and repulsion. Thus the classic Coulomb law of magnetic force was followed only at magnet separations of greater than 2mm.

Force-separation behavior and the high cost of these magnets may not justify their routine clinical use.

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Key Words

Force generation • Sm-Co magnets

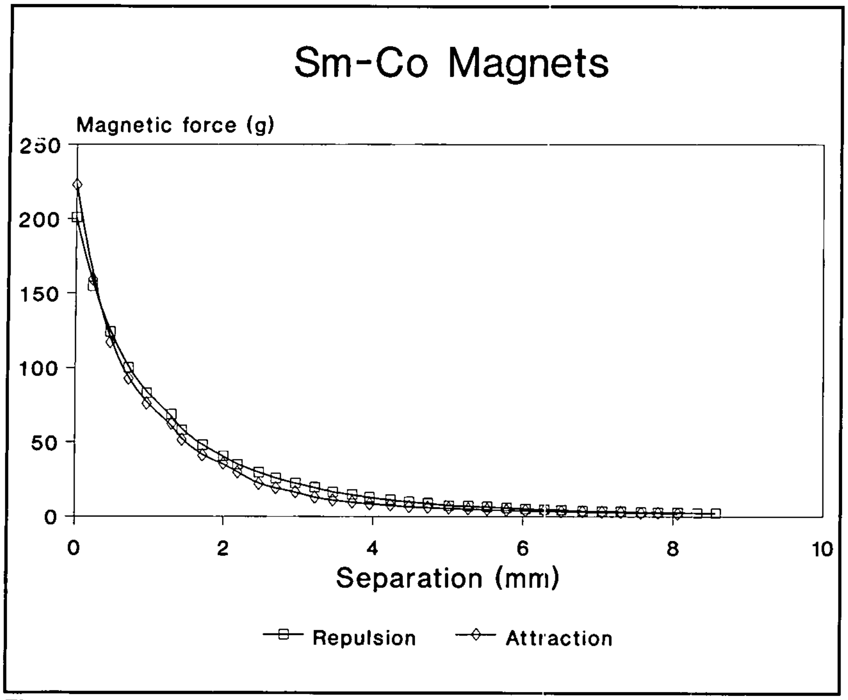

Figure 1

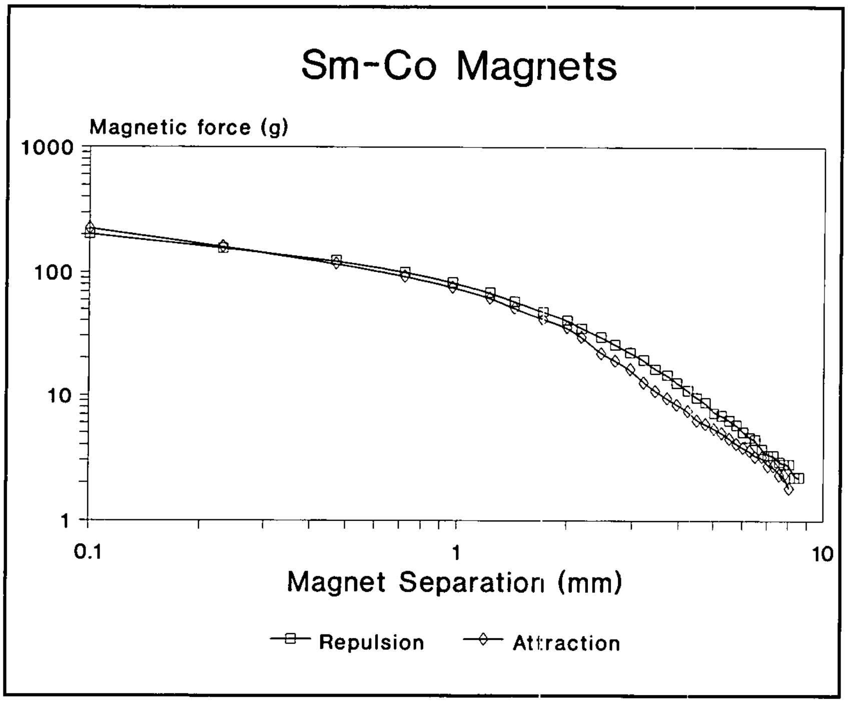

Figure 2

Figure 1
Typical variation in magnetic force between Sm-Co magnets in attraction and repulsion as a function of magnet separation

Figure 2
Typical plots of the logarithm of magnetic force against the logarithm of magnet separation (log-log plots) for Sm-Co magnets in attraction and repulsion

of a Unite-O-Matic FM 20 universal testing machine. The magnets were aligned with each other to within ±1mm and were adhered to the rods with Unite bonding adhesive (Unitek Corporation, Monrovia, Calif.). All forces were measured continuously by the internal load transducer of the testing machine and plotted as a function of crosshead movement (magnet separation) by the internal chart recorder of the test machine.

In repulsion tests, the magnets were separated from contact and positioned 1cm apart. The crosshead moved downward at a rate of 2.5mm/min and the force between the magnets was recorded simultaneously with the magnet separation. The direction of crosshead movement was then reversed and the force produced as the magnets were separated was measured. This procedure was repeated for all six pairs of magnets.

For the attraction tests, the same procedure was followed with the magnets initially in contact and the generated force between the magnets measured as they were separated. At 1cm separation, the crosshead was reversed in direction and the attractive force between the magnets was measured as they were brought back into contact.

Results

Typical force-separation curves for the attraction and repulsion tests on the samarium-cobalt magnets are presented in Figure 1. Very high forces, >200g, were generated at small separations while optimal orthodontic forces, in the range of 75g to 150g, were obtained over the separation range of 0.5mm to 1.5mm.

The relationship between force (P) and magnet separation (d), i.e. magnetic force = (separation)^n or $P=d^n$ was determined by plotting the data for the attraction and repulsion tests against magnet separation as log-log plots. Typical plots are given in Figure 2. The Sm-Co magnets exhibited two distinct regions of behavior in both repulsion and attraction, i.e. the log-log plots had two linear regions, one extending from contact (0mm) to a separation of 2mm, the second — with a different slope — extending from a separation of 2mm to 10mm. There was, however, very little difference between the linear force-separation and log (force)-log (separation) curves for attraction and repulsion, Figures 1 and 2. The slopes of the straight line portions of the plots give the values of exponent n in the force separation equation $P=d^n$.

At separations of d=0mm to 2mm, the mean exponent, n, in the force-separation equation was -0.41 for repulsion and -0.44 for attraction, an approximate inverse square root relationship between the force generated and the magnet separation. At separations of 2mm to 7mm, the mean exponent, n, was -2.10 for expulsion and -2.11 for attraction, an inverse square root relationship between force and magnet separation. Thus, the values of n varied with magnet separation, with the exponent having a value close to -0.5 at separations of 1mm to 2mm, and a value of approximately -2.0 at separations of 2mm to 7mm, Table 1.

Means and standard deviations were calculated for the values of n obtained from slopes of the two linear regions of both the attraction and repulsion tests. ANOVA and post-hoc Tukey hsd (honestly significant difference) tests showed no significant differences between the attractive and repulsive forces generated.

Table 1
Values of exponent n in the relationship force = (separation)^n

	Separation (mm)	Exponent
Repulsion	0-2	-0.41±0.22*
	>2	-2.08±0.12*
Attraction	0-2	-0.44±0.02*
	>2	-2.11±0.07*

*mean value ± standard deviation

Discussion

A separation range of contact to 1cm was used in this study to fully characterize the system, although the recommended maximum separation of the magnets as supplied by the manufacturer is 6mm to 7mm. In clinical use, the magnets are reactivated at each patient visit, generally at 4 week intervals, so maximum tooth movement, and consequently magnet separation, in this period will generally be 2mm to 3mm.

Coulomb's law of force states that the force between two magnetic poles is proportional to their magnitudes and inversely proportional to the square of the distance between them and therefore the exponent n in the equation force=separation^n should have a value of -2.0. The data obtained in the present study indicate that the force between the Sm-Co magnets follows Coulomb's law of force only at separations ≥2mm. At separation <2mm, the force between the magnets approximates to an inverse relationship with the square root of the distance between magnets. Thus, the force between the magnets, in both attraction and repulsion, is decreased at small separations by an order of magnitude. In contrast, at larger separations when Coulomb's law is followed, there is a much smaller change in magnetic force with changes in magnet separation. Other workers have indicated that the field interaction due to the approximation of two magnets results in a decrease in force less than the square of the distance between the magnets[4] but the actual variation in force with magnet separation was not reported.

The deviation from Coulomb's law observed in this study may be due to the small physical size of the magnets and their inherent strength, notably an interference in the magnetic field between the poles. In fact, Coulomb's law of force applies to single magnetic poles and the separation between them. However, in the present study, four strong poles are brought in close proximity due to the small size of the magnets and this appears to distort the magnetic field. In particular, the poles of the individual magnets are close to one another and although the magnets may be positioned in repulsion, for example, there will be some attraction to the opposite pole of each magnet with the other. The same effect will occur if the magnets are oriented in attraction and, in both cases, any misalignment of the magnets may greatly enhance this effect. The result of these interactions is that at small magnet separations the force generated is close to that recommended for optimum physiological tooth movement. At large separations, when Coulomb's law is followed, the magnetic force generated is lower than that required for optimum physiological tooth movement and the magnets may be less effective. This variability in behavior places in question the use of magnets as an effective orthodontic appliance.

Conclusions

Samarium-cobalt magnets were found to have two distinct regions of behavior: at separations >2mm, the classical Coulomb's law of magnetic force was followed; at 0mm to 2mm separation, an approximately inverse square root relationship was followed and the effective force was reduced to values closer to those required for physiological tooth movement.

In clinical use, with intervals of 1 month between appointments, the magnets produce forces that decrease from approximately 200g at contact to 40g at 2mm, with a rapid decrease in force at greater separations. While the magnets can provide forces in the range of 75g to 100g, sufficient to produce tooth movement, the objective of light, continuous force would appear impossible. However, magnets can be used to closely approach forces in the range of 75g to 100g if a 0.75mm shim is placed between the magnets when they are activated and shorter intervals between activations are used. As currently designed, samarium-cobalt magnets are practical only for use in the posterior segment due to their size. In addition, using the magnets in attraction is risky because as the teeth get closer together, the forces between them increase markedly and the physiological consequences may be less predictable. Finally, the magnets' relatively high cost may further preclude their widespread clinical use.

The findings of this study indicate that the use of Sm-Co magnets for routine orthodontic applications may not be justified.

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Author Address

Dr. J.A. von Fraunhofer
School of Dentistry
University of Louisville
Louisville, KY 40292

JA von Fraunhofer is Professor of Biomaterials Science, School of Dentistry, University of Louisville.

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