Eur. J. Prosthodont. Rest. Dent., Vol.15, No. 1, pp 7-12
Printed in Great Britain

Breakaway Forces of Flat and Domed Surfaced Magfit™ Implant Magnet Attachments

V. Chopra*, B. J. Smith†, H.W. Preiskel‡, R. M. Palmer§ and R. Curtis¶

Abstract - *The aim of this in vitro study was to compare the resistance to separation (breakaway force) of flat (Magfit™-IP-BF) and domed (Magfit™-IP-BD) implant magnet attachments subjected to non-axial forces. The separating forces were applied by an Instron Universal Testing Instrument to single magnet attachments at angles of 0°, 2°, 5°, 10°, and 20° from the axial line of the components (angle of pull) and at crosshead speeds of 0.5mm/min and 50 mm/min. The breakaway forces were significantly (p<0.0001) inversely related to the angle of pull for both flat magnets and for domed magnets. At the slow crosshead speed, the breakaway forces recorded for the domed magnets were significantly greater than those recorded for the flat magnets for angles of pull greater than 5°. At the faster crosshead speed, the breakaway forces recorded for the domed magnets were significantly greater than those recorded for the flat magnets for angles of pull greater than 2°. This apparent superiority of domed magnets under non-axially directed separating forces could influence the choice of magnet attachment for implant overdentures as intraoral displacing forces are multidirectional. Domed magnets may also be advantageous where implants are not parallel.*

KEY WORDS: Breakaway force, angle of pull, implant magnet attachments, flat magnets, dome magnets, overdentures

INTRODUCTION

Magnets have been used to aid retention of dentures for over fifty years. Freedman[1] placed magnets in the occlusal surfaces of complete denture with like poles adjacent so that the repulsion would seat each denture. Behrman[2] embedded magnets in the jaw with other magnets in the overlying denture base with opposite poles adjacent so that the attraction would seat the denture. Magnets appeared to be first set in the roots of teeth to provide direct retention for overdentures in the 1970s[3] and on implants in the following decade[4]. One of the advantages claimed for magnet attachments was that the magnets placed less stress on the implants when compared with ball attachments and bar/clip attachments[5].

The relationship between the retention of magnet attachments and other variables has been investigated comprehensively *in- vitro* but the separating forces have been applied in an axial direction usually at a separation speed of 0.5 mm per minute; relatively little research has been carried out with forces applied in a non-axial direction.

Five different implant overdenture attachments, including a closed field magnet system, were evaluated by Petropoulos et al[5]. The dislodging forces were applied in vertical and oblique directions. The authors measured the peak load (maximum force developed prior to separation), break load (the force that caused separation of the components), displacement at peak load, and displacement at break load. The release period (the time over which an attachment loses its retention), was calculated. For vertically directed forces, the magnet had the lowest values. With oblique forces the magnet had the lowest measured retention and the slowest release period. The clinical implication attributed to this slow release period was that it would give the magnet sufficient time to reseat itself when a denture was dislodged.

In 1999, Nestle *et al*[6] measured forces between various types of magnetic inserts and secondary magnets used for retention of extraoral prostheses to examine the influence of varying height, form and angle. The authors observed that the breakaway force decreased as the angle of pull increased. At an angle of pull of 75°, the force decreased to nearly half of the initial value (mean force in axial direction was 1.8 N). Although spherical magnet attachments were investigated, it was not clear whether or not there were curved contact surfaces between the magnetic inserts and the spherical secondary magnets.

Yatabe *et al*[7] conducted a study with three different sized magnetic attachments set at angles ranging from 0° to 30°. A fall in retentive forces was observed with increasing angles that was not significant in the 10° range. Hence they concluded that the magnetic assembly should be set up within 10° to the direction of removal of the denture. The forces were measured at a separation speed of 0.5mm/min., a speed at which the maximum retentive force for magnets has been noted[8].

Zhao et al[9] carried out a study in which four magnetic keepers were installed at four different sites on an edentulous model at 0°, 10°, 20° and 30° in 8 different directions. The breakaway forces were measured at 1mm/min and 200 mm/min at vertical (90°) and anteriorly inclined (60°) directions. The authors reported an increase in breakaway forces from 0-10° by 5.7%-16.93% and concluded that, by

* BDS, MDS, MSc
† BDS, FDSRCS, MSc
‡ BDS, MDS, MSc, FDSRCS
§ BDS, PhD, FDSRCS
¶ DIC, PhD, BSc, FADM, CEng, FIMMM

changing the direction of magnetic attachments, the retention of overdentures could be adjusted.

Implant magnet attachments are available commercially as flat surfaced or dome surfaced. Domed magnets do not appear to have been tested for non-axially directed forces as previous studies[5,7,9] have used flat magnets.

The purpose of this study was to determine whether flat surfaced or dome surfaced magnetic attachments demonstrated greater resistance to separation (breakaway force) under the application of non-axial forces. Two different speeds of separation were used: one speed was 0.5 mm/min for comparison with previous studies; the other was 50mm/min, closer the speed of mandibular movement[10] .

MATERIALS AND METHODS

The magnets used in this study were from the Magfit-IP™ magnetic system which was designed specifically for implant-stabilized overdentures. In this system, the magnet is a permanent magnet made from Neodymium-Iron-Boron with a magnetic circuit design of a sandwich closed circuit. As the alloy has a low corrosion resistance, the magnet is set between two yokes with a stainless steel case. The yokes and case are made from AUM 20 alloy, a magnetic stainless steel which is chromium rich, nickel free and has a high corrosion resistance.

There are three types of magnetic attachments in the system: flat (Magfit-IP-BF), domed (Magfit-IP-BD), and cushioned (Magfit-IP-BS). For this study, the flat and domed magnets were used. The "attractive force" stated by the manufacturer is 750gf and 600gf for the flat and domed magnets respectively. The magnetic leakage field is stated as 0.004 Tesla and 0.003 Tesla for the flat and domed magnets respectively. The attachment consists of the magnet and a keeper. In clinical use, the magnet is held by mechanical retention in the denture base. The keeper is attached to the implant abutments by a screw. A recent modification allows direct connection of the keeper to some designs of implants.

In this study, an Instron Universal Testing Instrument was used to apply force to separate the two parts of the magnet attachment. The keeper was attached to the fixed lower platform of the machine. The magnet was attached to the load cell on the moving upper part of the machine. The Instron had a separate recorder and chart-drive unit from which the recordings of breakaway force were made.

Five test samples of the flat magnet (Magfit™-IP-BF) and five test samples of the domed magnet (Magfit™-IP-BD) were assembled in the following manner. A 5mm diameter non-magnetic metal tube (nickel silver alloy) with an internal diameter of 4mm was sectioned into 10mm lengths. For each piece, the cut surfaces were prepared so that they were smooth and perpendicular to the long axis of the tube. Each 10mm section was placed vertically on a glass slab and filled with auto-polymerizing acrylic resin. Then, a 1.5 mm diameter hole was drilled into the centre of one end of the acrylic resin filled tube and a standard brass hook was then screwed into the prepared hole. A magnet was attached to the other end of the tube with autopolymerizing acrylic resin so that the magnet face was perpendicular to the long axis of the tube (Figure 1).

A single keeper mount was prepared in the following manner. A 25 mm length was cut from a non-magnetic 5mm x 5mm square cross-section metal tube (nickel silver alloy). The cut surfaces were prepared so that they were smooth and perpendicular to the long axis of the tube. The 25mm section was placed vertically on a glass slab and filled with autopolymerizing acrylic resin. A Nobel Biocare standard abutment replica DCB 175-0 was inserted into the end of the tube while the acrylic resin was still fluid and with the face of the replica perpendicular to the long axis of the tube. The resin was allowed to set undisturbed and then the magnet keeper was screwed onto the abutment replica (Figure 2)

To hold the keeper mount securely onto the fixed platform of the Instron, a cobalt chromium abutment mount jig was custom-made in two halves. This jig was of the same dimensions as the Instron instrument clamp. To determine and set the angulation of the magnet assembly, a gauge was custom prepared such that it slid into and fitted tightly over the end of the clamp plates. The gauge could be readily attached and detached from the clamp plate and was fitted on one of the clamp plates prior to positioning of the jig.

For each test, the magnet sample was hooked via a chain to the load cell on the upper moving platform of the Instron instrument. The keeper mount was fastened at different angles using the custom angulation gauge (Figure 3).

For each magnet, ten measurements of the breakaway force were conducted at five different angles of pull (0°, 2°, 5°, 10° and 20°) and at two speeds of separation (0.5mm/min, 50mm/min).

RESULTS

Table 1 shows the means of the fifty measurements of the breakaway forces for the five single flat magnet attachments and the five single domed magnet attachments at fast and slow crosshead speeds of the Instron Universal Testing Instrument at each of the five different angles**.**

At a crosshead speed of 0.5mm/min, the flat magnets demonstrated a higher mean breakaway force at 0°, 2°and 5° than for the domed magnets but beyond that angle the breakaway forces recorded for the domed magnets were higher. At a crosshead speed of 50mm/min, the breakaway forces for the single flat magnets were greater than for the single domed magnets at angles of pull of 0° and 2°. For angles of pull of 5°, 10° and 20°, however, the breakaway forces for the domed magnets were significantly greater than for the flat magnets.

Analysis of Variance (ANOVA) was carried out to determine the significance of differences. The difference in the mean breakaway force between the flat and domed magnets was found to be highly significant ($p<0.0001$) at every angle of pull and at both speeds of separation. Analysis of Variance was also carried out to determine whether or not any of the interactions between the various variables involved (i.e. magnet and angle, magnet and speed, angle and speed) affected the main comparison. The difference between the two types of magnets remained highly significant ($p<0.0001$). The inter-sample variation as expressed by the values for the standard deviations was greater at the lower

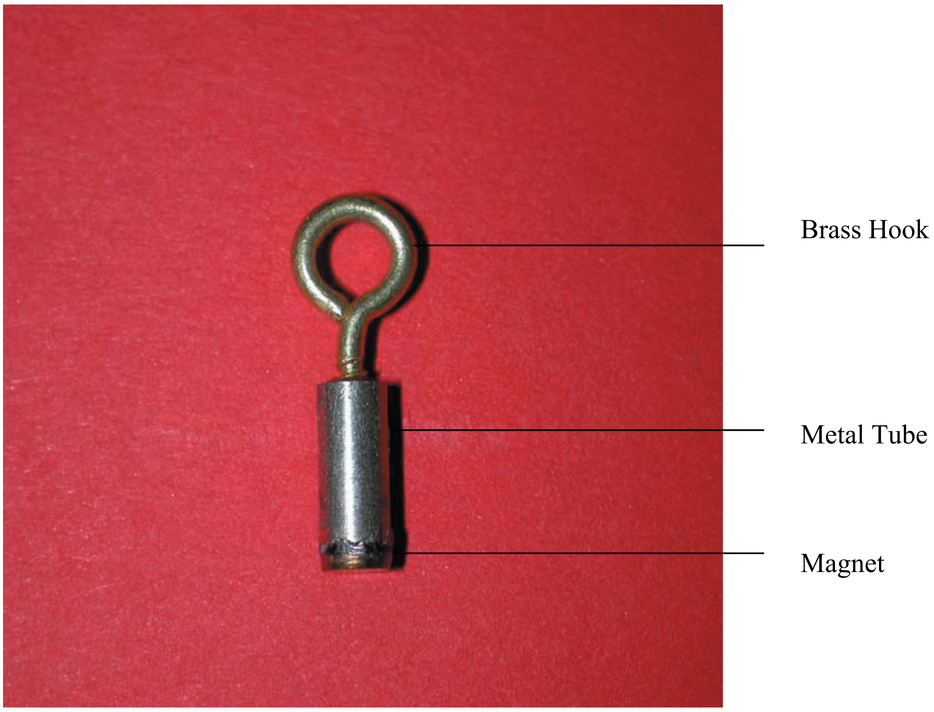

Figure 1. *Magnet mount*

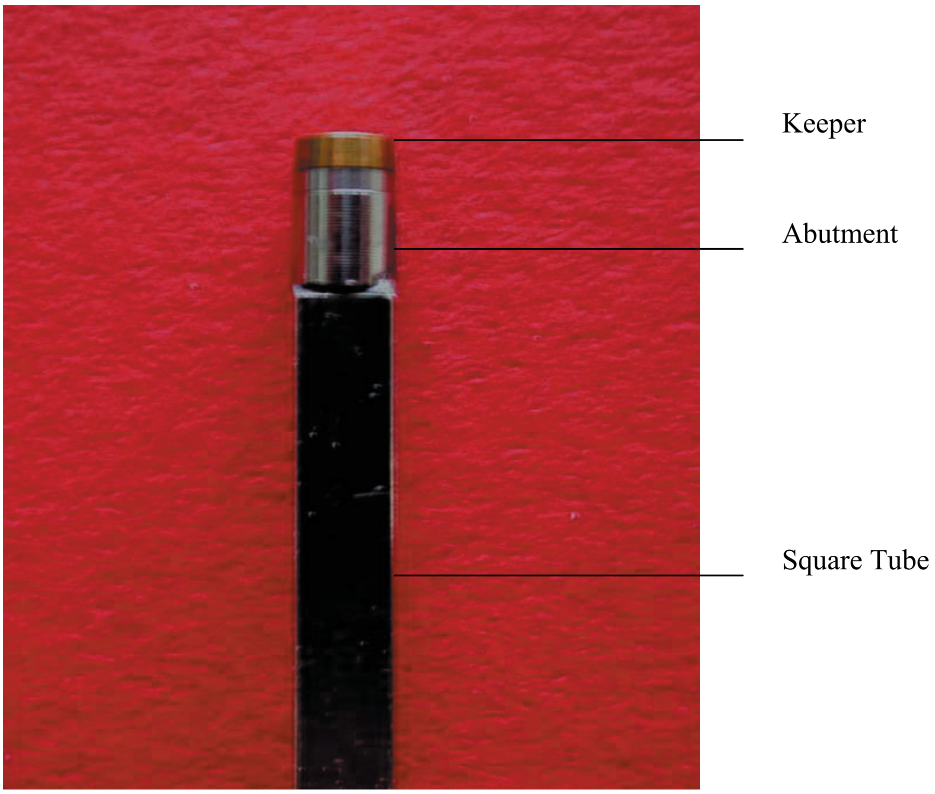

Figure 2. *Abutment/Keeper assembly*

Figure 3. *Instron 1193 with Experiment set-up*

Table 1. Mean breakaway forces in Newtons of single flat magnets and single domed magnets at slow (0.5mm/min) and fast (50mm/min) crosshead speeds, and at different angles of pull.

	Magfit-IP-BF (Flat magnets)		*Magfit-IP-BD (Domed magnets)*	
Angle	*0.5mm/min Mean(SD)*	*50mm/min Mean(SD)*	*0.5mm/min Mean(SD)*	*50mm/min Mean(SD)*
0°	6.3(0.5)N	2.9(0.4)N	4.1(0.4)N	2.1(0.6)N
2°	5.4(0.6)N	2.6(0.4)N	4.1(0.5)N	2.3(0.5)N
5°	3.7(0.5)N	2.0(0.5)N	3.4(0.6)N	2.3(0.4)N
10°	2.1(0.1)N	1.5(0.4)N	3.0(0.3)N	2.1(0.3)N
20°	1.3(0.1)N	1.1(0.2)N	1.8(0.2)N	1.5(0.1)N

angles for both flat and domed magnets at both crosshead speeds. The variation among the five domed magnets was greater than that of the flat magnets. (Table 1)

DISCUSSION

In the present study, the breakaway force was recorded for two speeds of separation of the magnet attachments. The breakaway force was the force required to cause initial separation of a magnet from its opposing attractive element (in this case the keeper), and its magnitude gave an indication of the amount of retention that was present when the magnet was in contact with the keeper. The slow speed of 0.5mm/min was the minimum possible crosshead speed on the Instron instrument and allowed the maximum breakaway force to be recorded for the magnet systems. The faster speed of 50mm/min was selected to be closer to the rate of movement of the mandible away from the maxilla during mastication[8,10]. Since intraoral forces displacing dentures are not limited to those in an axial direction, for the investigation of the magnet attachments different angles of pull were selected, ranging from 0° to 20°.

The breakaway force of all the magnets was significantly lower at the crosshead speed of 50mm/min compared with the values determined at slow speed of separation. This was consistent with the results of earlier studies[8,10]. For closed field magnets such as those used in this study the magnetic lines of flux broke down rapidly as the distance between the magnet and the keeper increased. At 50mm/min, the critical distance was achieved in a shorter period of time and hence the force recorded was lower.

The drop in the force values was greater at the lower angles of pull with the difference being greater than 50% at 0° and 2° for the flat magnets. This difference in force magnitude decreased as the angles were increased such that at 20° the difference was reduced to 0.2N and 0.3N for the flat and domed magnets respectively. Whereas Sarnat[10] reported four times smaller values, Akaltan and Can[8] reported smaller differences at the faster speed of separation.

It was also observed that, at the faster speed of separation, the breakaway force was fairly constant at varying angles of pull for the domed magnets and up to 10° the force remained at approximately 2N. As any force acting in the mouth during mastication would probably fall in the fast separation range, these values should have greater clinical relevance than those with the slow crosshead speed.

To maintain a denture in position on the alveolar ridge, the breakaway force must exceed the displacing force. From clinical observations, Gillings[11] suggested that magnetic units that provide 4.9N of retention would be sufficient and reported that patients with more than four magnetic units had difficulty in removing their dentures. According to the manufacturers, the retentive force to be provided by the flat and dome magnets is 750gm (7.35N) and 600gm (5.9N) respectively.

In both magnet types, the maximum force values were obtained with axially directed forces (i.e. 0°) and fell significantly as the angle of pull was increased to as little as 2°. The mean values for the maximum breakaway force in the present study were 6.3N±0.5 and 4.1N±0.4 for the flat and domed magnets respectively (Table 1).

This represented a difference of about 1N for the flat magnets and 2N for the domed magnets. Since these are the values at the slow speed of separation, and taking into account the inter-sample variation observed in this study, the decision as to the number of magnets required for retention of a denture must be made with care.

It was also seen that the inter-sample variability was greater for the domed magnets. The cause for this variability could not be precisely explained by this study although some degree of experimental error introduced during determination of the angle of pull (eg error of parallax) may have contributed to this inter- sample variation.

An inverse relation between the breakaway force and angle of pull at both speeds of separation was shown for the flat magnets. This was seen for all except one sample, which recorded an increase in force at 2° angle of pull. This was in agreement with the results of studies by Nestle *et al*[6] and Yatabe *et al*[7] but was in contrast to those of Zhao *et al*[9]. It should be noted that the magnet systems for all these three studies were different.

For the domed magnets, a similar decrease in breakaway force with an increase in angle of pull was observed at the slow speed of separation but as mentioned earlier, this was not the case at the faster speed of separation. Furthermore, the breakaway force values for the domed magnets significantly exceeded those of the flat magnets at angles greater than 5°. Thus, flat magnets produce higher breakaway forces than domed magnets up to 5° ($p<0.0001$) but domed magnets perform significantly better at higher angles of pull (Figure 4).

Another difference noted was the greater consistency in the force values for the domed magnets rather than the flat magnets as estimated by the standard deviation values. The explanation for this relative lack of variability may be attributed to the ability of the domed magnets to accommodate changes in angulations.

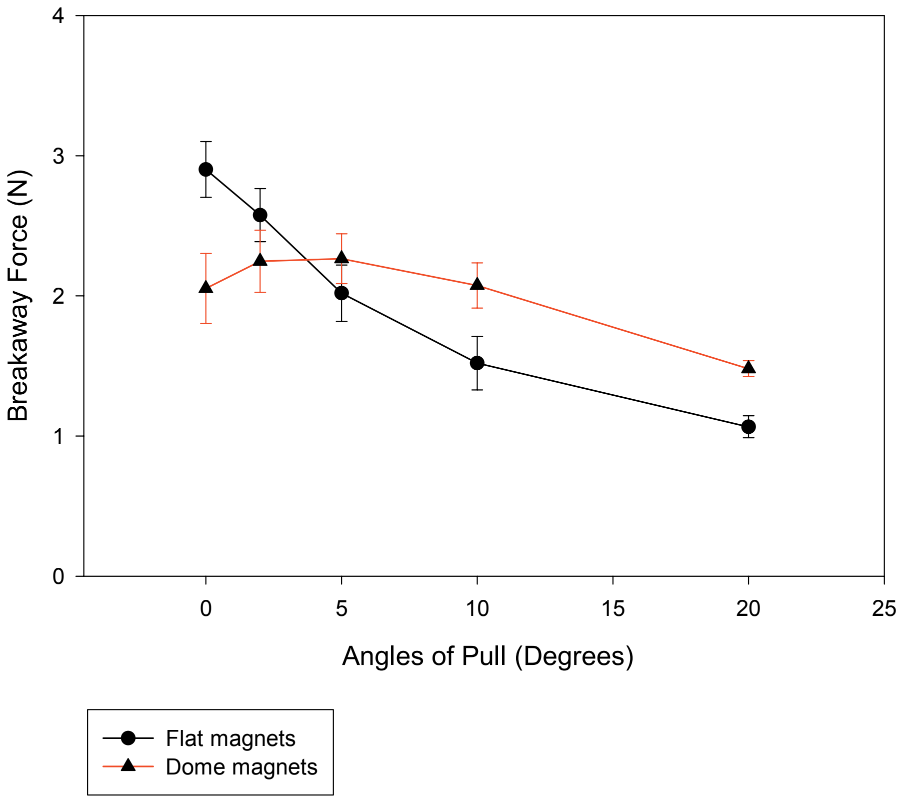

Figure 4. *Graph to show the comparison between the mean breakaway force (with standard error bars) of the dome magnets at a crosshead speed of 50mm/min., at various angles of pull*

The magnets used in this study appear to have superior retentive qualities than those tested in previous studies at the faster speed of separation. The breakaway force of the magnets was seen to be very sensitive to change in angulation of pull for both flat and dome magnets. At angles of pull of 0°, the flat magnets were significantly superior to the domed magnets but this trend was reversed at higher angles of pull suggesting that, in the clinical situation, it would be beneficial to use the domed magnets rather than the flat as denture displacing forces are multidirectional. In addition, domed magnets could be advantageous when the implants were placed at angles greater than 5º to each other.

The magnitude of the force for both flat and domed magnets fell to below 2 N at angles of 20º and this could influence the number of magnet attachments required to achieve denture retention. Since single domed magnets performed better at greater angles of pull, future studies should be carried out on paired domed magnets in a simulated clinical situation.

CONCLUSIONS

The following conclusions can be drawn from the present study:

1. Flat-surfaced magnets (Magfit™-IP-BF) demonstrated a higher breakaway force than dome-surfaced magnets (Magfit™ -IP-BD) for axially directed forces.
2. The breakaway force was influenced by small changes in angles of pull at slow speeds of separation with a decrease in breakaway force at higher speeds of separation, but the influence of speed on force magnitude decreased with increase in angulation.
3. Dome-surfaced magnets (Magfit™-IP-BD) were significantly different from flat-surfaced magnets (Magfit™-IP-BF) with respect to the breakaway force, behaviour, and performance at different angles of pull and performed significantly better at angles of pull greater than 5º.
4. As denture displacing forces are multidirectional, it may be clinically beneficial to use the dome surfaced magnets rather than the flat surfaced magnets especially when the implants are placed at angles greater than 5º to each other.

ACKNOWLEDGEMENTS

The authors would like to thank Davis, Schottlander and Davis Ltd, Letchworth Garden City, UK, and the Aichi Steel Corporation, Aichi, Japan for supplying the Magfit™ implant magnet attachments investigated in this study. The authors would also like to thank Dr R Wilson, Mr W Thomas and Mr R Mallet for their help in this study.

MANUFACTURERS' DETAILS

- Aichi Steel Corporation, Aichi, Japan 476-8666
- Model 1193, Instron, Bucks, UK
- Graphic 1002 chart recorder, Lloyd Instruments, Fareham, Hants, UK
- Nobel Biocare AB, Göteborg, Sweden

ADDRESS FOR CORRESPONDENCE:

Dr V Chopra, 10 Hampton Close, Cottenham Park Road, LONDON, SW20 ORY. E-mail: chopraviraj@hotmail.com

REFERENCES

1. Freedman, H. Magnets to stabilize dentures. *J. Am. Dent. Assoc.*, 1953; **47**: 288-297
2. Behrman, S.J. The implantation of magnets in the jaw to aid denture retention., *J. Prosthet. Dent.,* 1960; **10**: 807-841.
3. Gillings, B.R.D. Magnetic retention for complete and partial overdentures. Part I. *J .Prosthet. Dent.,* 1981; **45**: 484-491
4. Ampil, J.P., Wegmann, C.S., Gambrell, K. Use of magnets for staple mandibular implants. *J. Prosthet. Den.,t* 1986; **55**: 367-369.
5. Petropoulos, V.C., Smith, W., Kousvelari, E. Comparison of retention and release periods for implant overdenture attachments. *Int. J. Oral Maxillofac. Implants,* 1997; **2**: 176-185
6. Nestle, B., Lukas, D., Schwenzer, N. Retention forces of magnets in endosteal implants used for facial prosthesis. *Int.J. Oral Maxillofac. Surg* .,1999; **28**: 41-44.
7. Yatabe, M., Mizutani, H., Nishiyama, A., Kaketa, T., Kotake, M., Kim, X., Ohyama, T. Attractive force of magnetic attachment influenced by its separated direction. *J. Dent. Res.,* 2001; **80**: 713
8. Akaltan, F., Can, G. Retentive characteristics of different dental magnetic systems. *J. Prosthet. Dent.,* 1995; **74**: 422-427,
9. Zhao, Y., Sugimoto, T., Hiranuma, K., Tanaka, Y. The study of influence of set angle and direction of magnetic attachments to retentive force of complete overdenture. Personal communication, Aichi Steel Corporation, Aichi Japan.
10. Sarnat, A.E. The efficiency of cobalt samarium (Co_5Sm) magnets as retention units for overdentures. *J. Dent.,* 1983;**11**:324-333.
11. Gillings, B.R.D. Magnetic dent.ure retention systems. In Preiskel H.W.(Ed):*Precision Attachments in Prosthodontics: Overdentures and Telescopic Prostheses Vol2.*Quintessence Publishing Company, London, 1985; pp191-227.