Retentive force of combined sandwich-type magnetic assemblies

M. Takahashi[1], G. Togawa[1], M. Kanyi[2], K. Ishikawa[1, 3] Y. Takada[1]

[1]Division of Dental Biomaterials, Tohoku University Graduate School of Dentistry, JAPAN
[2]Moi Teaching and Referral Hospital, KENYA
[3]Tohoku University Hospital, JAPAN

Introduction

Dental magnetic attachments are often used as retentive elements in partial and complete dentures. They can also be utilized in implant over dentures such as 2-IOD and 4-IOD. From 2021, the Japanese insurance system committed to cater for cost of dental magnetic supported appliances[1)]. Its usage is therefore expected to rise in future. Magnetic attachments manufactured in Japan are predominantly a combination of magnetic assembly and keeper. A magnetic assembly exhibits closed magnetic circuit which is characterized by high retentive force despite its small size. Leakage of magnetic field associated with the closed circuit is minimal. On the other hand, products made in other countries utilize both closed and open magnetic circuit type magnets. To overcome poor corrosion resistance of rare–earth magnets, magnets used in dentistry are covered with stainless steel or titanium[2)]. A magnet is simple and easy to manufacture compared to magnetic assembly. However, its open magnetic circuit feature is associated with high leakage of magnetic field, and low retentive force relative to its size. In order to compensate for the weak retentive force of magnet-keeper combination, it may be beneficial to combine two magnets. In practice, there are three possible combinations of dental magnetic attachments: magnetic assembly to keeper, magnet to keeper, and magnet to magnet.

The magnet to magnet combination exhibits a retentive force greater than that of magnet-keeper combination. It is therefore postulated that two magnetic assemblies combined would also yield higher retentive force than magnetic assembly to keeper. However, there is no research on retentive force when combining two magnetic assemblies.

The two types of magnetic assemblies for application as dental magnetic attachments which exist are cup-yoke and sandwich type[3)]. It is difficult to combine two cup-yoke type of magnetic assemblies because the contact mating faces are of similar polarity causing repulsion (Fig. 1). Sandwich types are easy to combine due to the attraction force exhibited by the unlike poles which make up mating faces (Fig. 2). This study explored the possibility and characteristics of a new combination that involves two sandwich-types of magnetic assemblies.

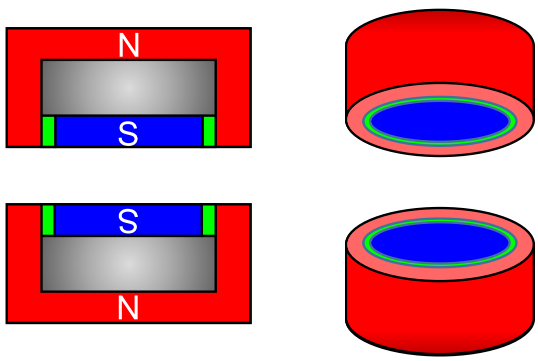


Fig. 1 Combination of cup-yoke type of magnetic assemblies

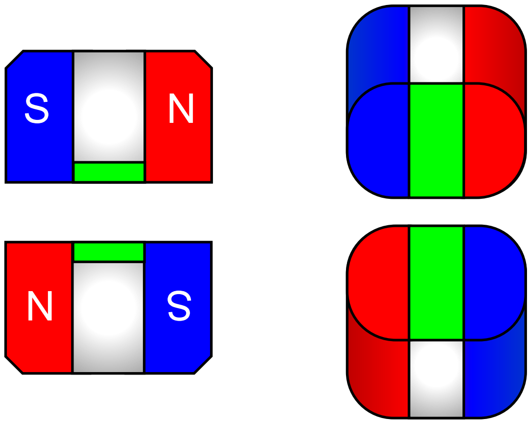


Fig. 2 Combination of sandwich type of magnetic assemblies

Objective

The aim of this study was to explore possibility of combining two sandwich-type magnetic assemblies and investigate the retentive force characteristics. A combination of magnetic assembly and keeper, which forms the ordinary magnetic attachment, was used for comparison.

Materials and Methods

1. Dental magnetic attachment

Oval sandwich-type dental magnetic attachments (MAGFITEX600W, 3.8 mm major axis and 2.8 mm minor axis length, Aichi steel Corp.) were used in this study. The magnetic assembly was either combined with a keeper or another magnetic assembly. The mating faces were placed in contact with different polarities across each other (Fig. 2). Magnetic keeper was paired up with magnetic assembly to represent the ordinary magnetic attachment.

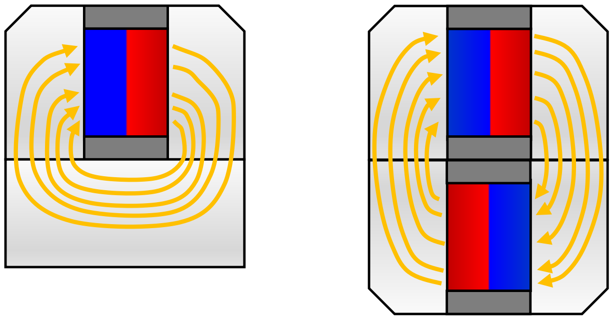
2. Procedure of retentive force measurement

The retentive force measuring device used in this study matches the description in ISO 13017:2020[3]. The device was connected to a digital force gauge (ZPS, Imada) and retentive force measured at crosshead speed of 2 mm/min. recording was done at a sampling rate of 1 kHz. Applying the known time and speed values, distance was calculated then a retentive force curve generated. The experiment begins when the magnetic assembly has its center aligned to that of keeper or second magnetic assembly. The measurements were done at intervals of 100 μm horizontal displacement, along the major and minor axis direction, of keeper or second magnetic assembly. The measurement is terminated when the magnetic assembly completely separates from its keeper or second magnetic assembly.

Results and Discussion

1. Retentive force of aligned magnetic attachments

The retentive force of a magnetic assembly paired with keeper or second magnetic assembly was 5.26 N and 6.45 N, respectively. Therefore use of a second magnetic assembly instead of keeper raised the retentive force by 1.23 times. This is attributed to the shorter distance between the magnetic poles of two magnetic assemblies (Fig. 3b) compared to magnetic assembly and its keeper (Fig. 3a). Additionally, the volume of the magnet is doubled, and the energy of the magnet increased causing an enhanced effect. However, due to saturation of the cup yoke's magnetic flux density, the retentive force is not doubled. Magnets whose design involves closed magnetic circuit are characterized by small size and relatively large retentive force. The force can be further enhanced through combination of two magnetic assemblies.



(a) (b)

Fig. 3 Schematic diagram of magnetic flux flow in the magnetic attachments (a) combination of magnetic assembly and keeper, (b) a pair of magnetic assemblies

2. Decline of retentive force upon complete separation of mating face

Retentive force curves for the two set up combinations are shown in Fig. 4. The displacement position at a time when the mating faces separate is denoted as 0 mm. For both scenarios, the retentive force values decreased with increasing distance which corresponds to displacement of the magnetic assembly away from keeper or second assembly. However, the rate of decline was moderate when two magnetic assemblies were paired up compared to the one with keeper. Although magnetic flux volume emitted from the assembly yokes is same, magnetic field lines are concentrated more towards the second magnetic assembly yoke than those that flow solely within the first assembly as shown in Fig 5. A combination of two magnetic assemblies offers a wider range of influence on the attractive force and is stable against air gap.

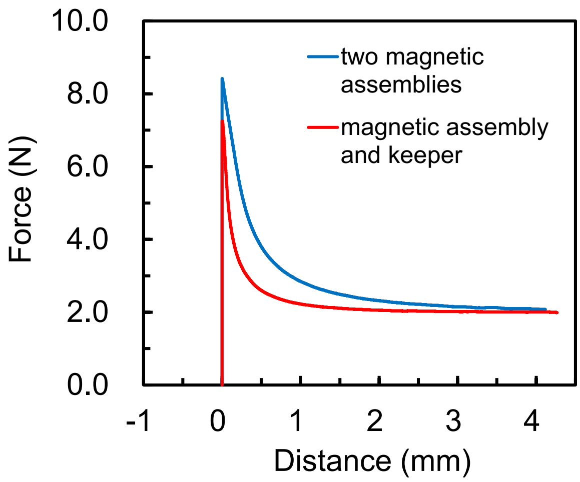
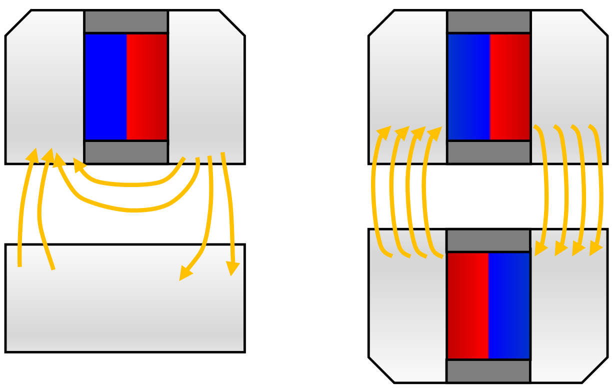


Fig. 4 Retentive force curve



(a) (b)

Fig. 5 Images of magnetic flux flow after separation of mating faces. (a) magnetic assembly and keeper combination, (b) pair of magnetic assemblies

3. Changes in retentive force against lateral displacement

Fig. 6 shows the change in retentive force when the second magnetic assembly was shifted in the major axis direction. The retentive force decreased gradually with increasing displacement. The loss in retentive force was linear at a displacement of 1.2 to 2.5 mm. This pattern was similar to that of the combination of the magnetic assembly and the keeper[4)]. The retentive force is therefore dependent on the contact surface area between the two magnetic assemblies upon displacement along the major axis direction.

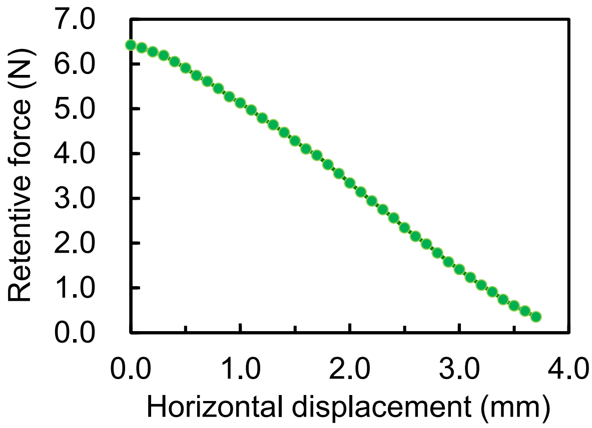


Fig. 6 Retentive force against displacement along major axis direction

Fig. 7 shows the changes in retentive force when displacement occurs along the minor axis direction. The retentive force decreased sharply upon displacement to reach 0 N at 1.5mm. Further displacement generated negative values which imply a repulsion of magnetic assemblies. This phenomenon was not observed in the magnetic assembly and keeper set up[4)].

As illustrated in Fig. 3, congruently matched magnetic assemblies have unlike poles in contact thereby producing an attractive force. Displacement along the minor axis direction, as shown in Fig. 8, creates varying scenarios in which some parts of magnetic assemblies are in attraction whereas others are in repulsion. The resultant force acting in a direction perpendicular to the mating face is measured and represents the retentive force. At the initial stages of displacement, the attractive force exceeds the repulsive force. At about 1.5 mm displacement, the two forces are equal resulting into 0 N retentive force. Further displacement yields a higher repulsive force compared to attractive force.

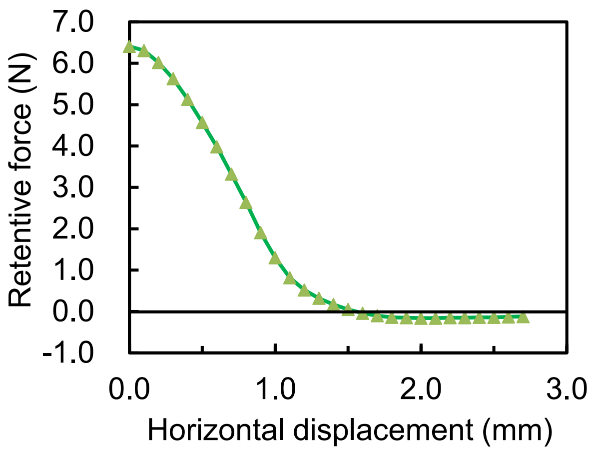


Fig.7 Retentive force against displacement along minor axis direction

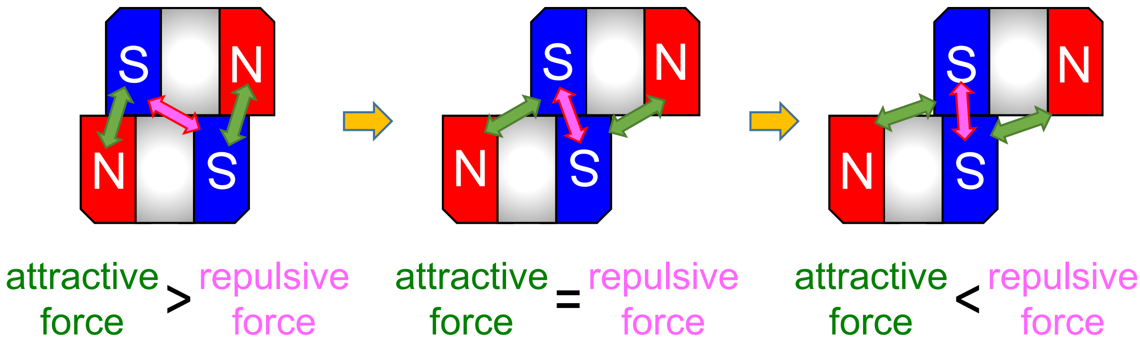
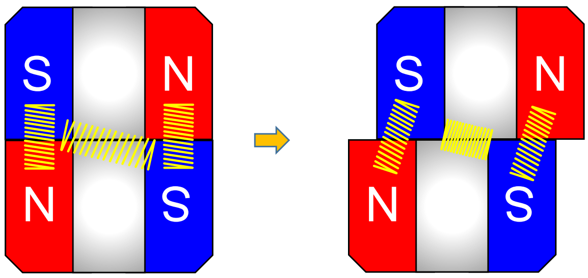


Fig.8 Images of forces between two magnetic assemblies in response to displacement along the minor axis direction

Besides the attractive and repulsive forces explained above; there also exists (lateral) forces that act in a direction parallel to the mating faces. Fig 9 demonstrates how attraction and repulsion forces act in a manner similar to closed and open coil springs respectively. A slight displacement (a→b) is accompanied by restoring force which acts like springs taking the set up back to the original position (b→a). Therefore, combining two magnetic assemblies yields a "restoring force" which counters the effect of minor lateral displacement.



(a) (b)

Fig. 9 Schematic drawing to illustrate spring effect of repulsion and attraction forces (a) well aligned, (b) slight displacement

4. Clinical application of combined magnetic assemblies

Dental magnetic attachment set up that involves two magnetic assemblies provides salient features which have meaningful applications in dentistry especially complete dentures. The spring like action by restoring force acts as a guide in proper alignment of magnetic attachments. It eases the procedure of incorporating magnetic assembly into denture. Higher retentive forces associated with magnetic assemblies compared to keeper of the same size offers improved denture stability. Erroneous inclusion of air gap has minimal effect as the consequent decrease in retentive force is gradual. The restoring force further promotes denture stability as minor denture displacement during function is automatically corrected. Major displacement of the magnetic attachment against abutment tooth in a horizontal direction triggers the repulsion forces which aid in removal of denture from the oral cavity. The concept of combining two magnetic assemblies is advantageous compared to use of assembly and keeper in terms of retentive force and stability.

Conclusion

The retentive force of a pair of magnetic assemblies was higher than that of magnetic assembly combined with keeper. The decline in retentive force was more gradual for the set up involving two magnetic assemblies compared to assembly and keeper. A pair of combined magnetic assemblies generates a restoring and repulsive force upon small and large displacements along the minor axis, respectively. It was established advantageous to combine two magnetic assemblies.

Acknowledgments

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