A feature of the retentive force of combination of two magnetic assemblies: a cup-yoke type magnetic attachment

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Introduction

Dental magnetic attachments are one of the retainers used for removable partial or complete dentures. They can be easily used with implants and are often used for implant overdentures such as 2-IOD and 4-IOD[1-3]. They have been covered by the Japanese medical insurance system since 2021, making it easier to design dentures with superior esthetics compared to dentures using only clasps[4,5]. Therefore, it is expected to become more and more popular in Japan. All dental magnetic attachments made in Japan are used in combination with a magnetic assembly and a keeper. The magnetic assembly is implanted in the denture, and the keeper is attached to the abutment tooth or implant. In the magnetic assembly, rare earth magnets are covered with magnetic and non-magnetic stainless steel to form a closed magnetic circuit[6]. Therefore, it has the advantages of great retentive force even in a small size and low leakage magnetic field. On the other hand, dental magnetic attachments manufactured outside of Japan include products that use open-circuit magnets, which are simply rare earth magnets with inferior corrosion resistance coated with stainless steel or titanium[7]. Open-circuit magnets have a simpler structure than magnetic assemblies and are easier to manufacture. However, open-circuit magnets have high magnetic field leakage and low retentive force for their size. To compensate for the weak retentive force, it is used not only in magnet-keeper combination, but also in combine two magnets. In summary, dental magnetic attachments are currently used in three different combinations: a magnetic assembly and a keeper, a magnet and a keeper, and a magnet and a magnet.

In a previous report[8], we focused on a previously unused combination of magnetic assemblies with magnetic assemblies. The combination of magnets with each other exhibits a grater retentive force than the combination of a magnet and a keeper. Therefore, it is expected that the combination of magnetic assemblies with each other also has a greater retentive force than the combination of a magnetic assembly and a keeper. The aim of previous study[8] was to explore possibility of combining two sandwich-type magnetic assemblies and investigate the retentive force characteristics. As a result, it was found that the retentive force was greater when the magnetic assemblies were combined with each other than with a keeper, and that the decrease in the retentive force was moderate after the mating faces separated.

Dental magnetic attachments are believed to protect abutment teeth from lateral forces because they do not exert strong retentive force against lateral forces that are harmful to the abutment teeth[6,9]. Therefore, in a previous study[10], we investigated the mechanical behavior of magnetic attachments against lateral forces by measuring the resistance and attractive force during lateral displacement between the magnetic assembly and the keeper, or between the magnet and the keeper. The results showed that the resistance force of magnetic attachments of commonly used sizes was about 1 N, indicating that they are more root-friendly abutments for abutment teeth than circumferential clasps or O-ring attachments. It was also found that the resistance force against the lateral force to displace the magnetic assembly from the keeper is related not only to the frictional force but also to the magnetic attraction force. In the combination of the magnet and the keeper, we found that when the magnet is displaced significantly, it moves itself in the direction where the center of the magnet and the keeper coincide. We named the force that tries to restore this position the "restoring force". In the study on the retentive force when sandwich-type magnetic assemblies are combined with each other, we did not measure the resistance force against lateral forces, but we confirmed a phenomenon that suggests the existence of a restoring force[8].

There are two types of magnetic assemblies for dental magnetic attachments: cup-yoke type and sandwich type[11]. Since interesting results were obtained by the combination of sandwich-type magnetic structures, we are also interested in the behavior of cup-yoke type magnetic structures with each other. However, unlike the sandwich type, it is difficult to combine cup-yoke type magnetic structures because the poles of the contacting parts of the mating faces are the same and therefore repel each other due to repulsion. If the magnetization direction of one of the magnetic assemblies is reversed, the cup-yoke type can be combined (Figure 1).

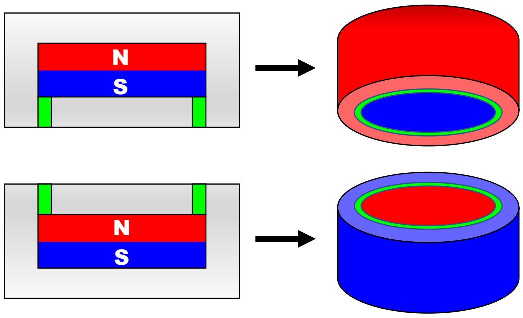


Fig. 1 Combination of cup-yoke type of magnetic assemblies

Objective

In this study, we prepared a magnetic assembly with the magnetization direction reversed, and investigated the retentive force and the characteristics of lateral displacement when two cup-yoke type magnetic assemblies are combined.

Materials and Methods

1. Dental magnetic attachment

A magnetic assembly of a cup-yoke type dental magnetic attachment (Physio Magnet 5213, Morita, Tokyo, Japan) was prepared. A magnetic assembly with the magnetization direction reversed from that of the commercial product was prepared by special order from the manufacturer, and combinations of magnet structures were used in the experiments.

2. Retentive force measurement

According to ISO 13017:2020[11], a digital force gauge (ZPS, Imada, Aichi, Japan) was connected to a retentive force measuring device, and the crosshead speed was set to 2 mm/min, and the retentive force (attractive force) of the combine two magnetic assemblies was measured while recording the retentive force curve. The retentive force was measured when the mating surfaces were in contact with each other at the exact position and when they were displaced horizontally from the exact contact position. The retentive force was measured for each 100 µm displacement of one magnetic assembly in the horizontal direction. The measurement was repeated until the magnetic assembly was displaced from the other magnetic assembly.

3. Measurement of the resistance force against the external force of displacement

As in previous study[10], an aluminum jig was attached to the upper and lower tables to create vertical surfaces facing each other in the retentive force measuring device, and the magnetic assemblies were fixed to the jig with cyanoacrylate adhesive. The magnetic assembly was pulled in the direction in which the mating surface slides at a crosshead speed of 1 mm/min, and the resistance force at that time was measured with a force gauge. The force was recorded at a sampling rate of 1 kHz until the magnetic assembly was removed from the other magnetic assembly. After the measurement, the time was converted to distance and a distance -resistance curve was generated.

Results

1. Retentive force

The retentive force of the combination of magnetic assemblies was 12.16 N. The retentive force of the combination of magnetic assembly and a keeper was 10.64 N[10]. The retentive force of the pair of magnetic assemblies was 1.14 times greater than that of magnetic assembly combined with keeper. A typical retentive force curve is shown in Figure 2. The results of the magnetic assembly and keeper combinations are also shown together. The position at the instant when the mating surfaces are separated is set to 0 mm. In both cases, the retentive force decreased as the distance between the mating surfaces increased. The retentive force between the magnetic assemblies decreased more moderate than magnetic assembly and keeper combinations after the surfaces separated.

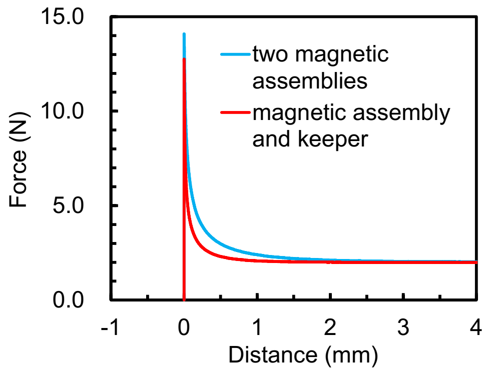


Fig. 2 Retentive force curve

2. Horizontal displacement and change in magnetic attractive force

The relationship between horizontal displacement and attractive force is shown in Figure 3. The attractive force decreased as the horizontal displacement increased, but the decrease in attractive force was not constant, and multiple inflections were observed.

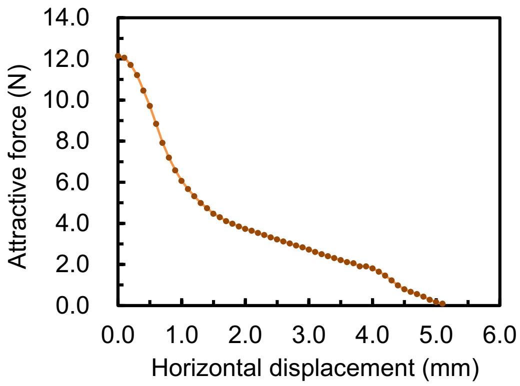


Fig. 3 Retentive force against displacement

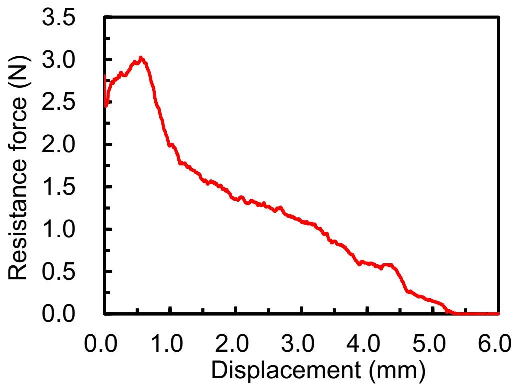


Fig. 4 The displacement -resistance force curve

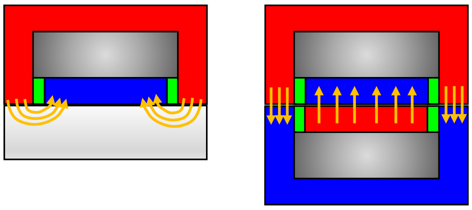
3. Resistance force to external forces that cause displacement

The distance -resistance force curve between two magnetic assemblies is shown in Figure 4. The horizontal axis represents the distance that the centers of the two magnetic assemblies were displaced along the mating surface from the state where their centers were coincident, and the vertical axis represents the resistance force at that position. The resistance force just before the magnetic assembly moved, i.e. the maximum static friction force, was 2.81 N. When the magnetic assembly started to move, the resistance force dropped to 2.45 N for a moment. After that, the resistance force increased to 3.03 N at a movement distance of about 0.55 mm, and further decreased with an increase in the movement distance, changing the inclination several times. The resistance force became zero when the travel distance exceeded 5.3 mm.

Discussion

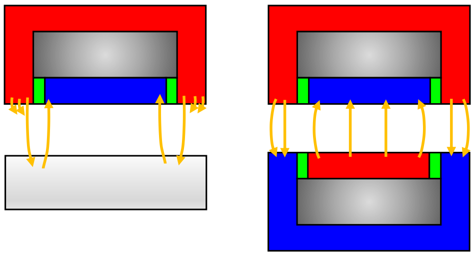
1. Retentive force

Use of a second magnetic assembly instead of keeper raised the retentive force by 1.14 times. This was the same as in the case of the sandwich type dental magnetic attachments[8]. The reason for this may be that the distance between the magnetic poles was shorter when the magnetic assemblies were combined with each other (b) than when the magnetic assembly was combined with the keeper (a), as shown in Figure 5. Another reason is that the volume of the magnets has doubled, and the energy of the magnets has increased. However, since the magnetic flux density of the yoke of the magnetic assembly has almost reached the saturation flux density, the retentive force is not doubled even if the energy is doubled. We found that although magnetic assemblies with closed magnetic circuit are characterized by their small size and great retentive force, the retentive force can be further increased by combining magnetic assemblies with each other. In addition, the decrease in retentive force after the mating surfaces separated was moderate for magnetic assemblies compared to magnetic assembly and keeper. As shown in Figure 6, the magnetic assembly is characterized by a small leakage magnetic field, and the retentive force quickly decreases to zero when the mating surface leaves the keeper. On the other hand, with magnetic assemblies, it is thought that the drop is moderate because the different poles of the magnetic assemblies attract each other even when they are separated from each other. Therefore, it can be evaluated that magnetic assemblies are more resistant to air gaps because they can attract each other farther away from each other (attractive force) even when they are separated. Accordingly, when magnetic assemblies are paired with each other, a stronger retentive force can be obtained in a smaller space, and they are also found to be more resistant to air gaps.



(a) (b)

Fig. 5 Schematic diagram of magnetic flux flow in the magnetic attachments (a) combination of magnetic assembly and keeper, (b) a pair of magnetic assemblies



(a) (b)

Fig. 6 Images of magnetic flux flow after separation of mating faces. (a) magnetic assembly and keeper combination, (b) pair of magnetic assemblies

2. Resistance force during lateral movement

In a similar past study[10], the coefficients of static and dynamic friction between the magnetic assembly and the keeper of a Physio Magnet 5213 were 0.17 and 0.13, respectively. The material used for the magnetic assembly and the keeper of this magnetic attachment is the same magnetic stainless steel. Therefore, it can be concluded that the coefficient of friction between the magnetic assemblies is the same as that between the magnetic assembly and the keeper. The frictional force is proportional to the normal force but independent of the contact surface area (Amonton's law). In this study, the attractive force of a magnetic assembly acts as the normal force. We therefore calculated the dynamic frictional force at each position where the magnetic assembly moved laterally, based on the data of the attractive force between the magnetic assemblies and the coefficient of dynamic friction. The results are shown in Figure 7 alongside the resistance force. The resistive force was larger than the dynamic frictional force calculated. This fact means that, as in the previous studies[10], the attraction force in the direction parallel to the mating surface due to the magnetic force between magnetic assemblies is included in the resistance force.

The difference between the resistance force and the dynamic friction force was calculated to obtain the laterally attraction force due to the magnetic force at each position. The maximum static friction force at each position moved sideways was calculated from the attractive force data and the static friction coefficient. The results are shown in Figure 8. As this figure shows, when the magnetic assembly is displaced by more than 0.5 mm, the attraction force due to the magnetic force exceeds the maximum static frictional force, and thus becomes a restoring force, restoring the magnetic assembly to the position where the center coincides with the center. Since the frictional force when the magnetic assembly is moving is the dynamic frictional force, it theoretically returns to the 0.3 mm position. Consequently, a large restoring force can be obtained when magnetic assemblies are paired with each other.

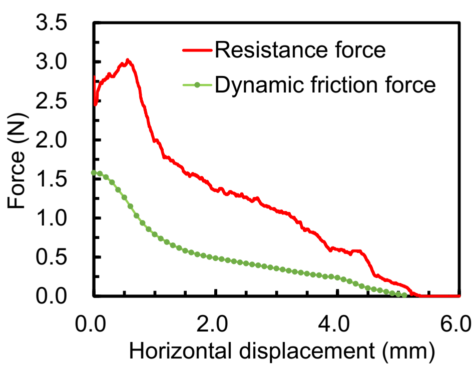


Fig. 7 Dynamic friction force and resistance force corresponding to different positions of horizontal displacement of magnetic attachment

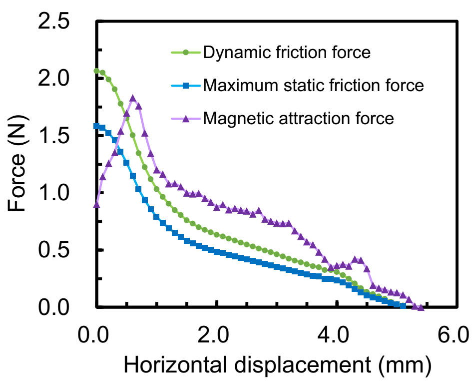


Fig. 8 Magnetic attraction force and maximum static and dynamic friction forces at each displaced position of magnetic attachment

3. Advantages in clinical application

Since dental magnetic attachments do not provide adequate retentive force if they are misaligned, alignment of the magnetic assembly when embedded in the denture is important, but the technique is difficult and requires a certain amount of sense and experience. However, when magnetic assemblies are used together, restoring forces guide both magnetic assemblies to the correct position (a position with no misalignment of the axes of both), so that anyone can easily and correctly align them without depending on their skills. When functioning, the retentive force is stronger than when combined with a keeper of the same size. Also, when the patient wears the denture, the restoring force guides the denture to the correct position. Since the weight of a complete denture is between 20 and 40 g and the frictional force is hardly increased, the restoring force is sufficient to move the denture. This is a great advantage for patients who have difficulty in taking adaptive action and for caregivers working in nursing homes.

Conclusion

The retentive force was greater when the magnetic assemblies were combined with each other than with the keeper, and the decrease in retentive force after the mating surfaces separated was moderate. The resistance force against lateral movement was greater than the dynamic friction force, and the difference, the laterally magnetic attraction force, exceeded the maximum static friction force. Therefore, it was found that combining cup-yoke type magnetic assemblies with each other facilitates alignment and provides restoring force.

Acknowledgments

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