



Research article

Ideal set-up angle between a pair of oval dental magnetic attachments for suppression of the loss in retentive force associated with horizontal displacement

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ABSTRACT

Two oval sandwich type magnetic attachments set up in various angulations and spacing, then the pattern of retentive force against horizontal displacement studied. A measuring device and methodology that matches ISO 13017 was used. A pair of magnetic attachments fixed on the same plane at a specific distance on the measuring device and set in various angulations. Retentive force readings of magnetic attachments in various setup positions against the horizontal displacement along the major or minor axis directions were taken. The pattern of decline in retentive force as horizontal displacement increased was different across the various set-ups. It was found that the decrease in retentive forces associated with horizontal displacement can be suppressed when the angle between the major axis and the direction of movement is as small as possible. Formation of a 90° angle between major axes of any pair of magnetic attachments led to nullification of the decline in retentive forces associated with displacement in any direction. Therefore, 90° is the practical, ideal set-up angle between any pair of dental magnetic attachments critical for suppression of the loss in retentive force associated with horizontal gap.

1. Introduction

Dental magnetic attachments are incorporated in removable prosthesis to provide retention [1, 2]. They are embedded within the denture base making them discrete and more esthetic compared to clasps. They are advantageous since lateral forces against abutment teeth hardly occur during the function [3, 4, 5, 6, 7]. Other elements like ball and locator attachments used to connect the over denture to implant do not possess the salient feature. Recently, magnetic attachments have been incorporated in implant-supported over dentures (IOD) such as 2-IOD or 4-IOD with reports of high patient satisfaction associated with IODs compared to complete dentures [8, 9, 10, 11].

It has been established that the occurrence of a space between the mating faces of a pair of magnetic attachment is associated with decline in retentive force. The space between mating surfaces which is referred to as an air gap may occur due to technical errors during fixation of magnetic assembly into denture base [5, 6, 7, 12]. However; actual measurements taken and three-dimensional finite element method of analysis

indicates that even in the absence of a space between mating surfaces; any horizontal displacement between the magnetic assembly and keeper lowers the retentive force [13, 14].

Magnetic attractive force (F) is calculated using Eq. (1) where C is the constant, B is the magnetic flux density, and S is the surface area [15]. An increase in the magnetic flux density enhances the magnetic attractive force much more compared to a similar increase in the surface area of a mating surface.

$$F = C \times B^2 \times S \quad (1)$$

Magnetic attachments can be classified into open and closed depending on the magnetic circuit. The open magnetic circuit type, utilized in a few countries, has its retentive force directly proportional to the contact area of the mating surfaces. Its retentive force can be calculated in accordance to Eq. (1). Contrastingly, retentive force of the closed magnetic circuit type which is common in most of the countries, is not directly proportional to contact surface area. This is due to the influence of the magnetic flux density on the retentive force. In a previous study

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[14], the retentive forces of round shaped cup-yoke type of dental magnetic attachments in different horizontal positions were measured and the relationship between retentive force and horizontal displacement investigated. The mechanism leading to the changes in retentive force was studied by means of modeling. Analysis of results acquired using mathematical formulas demonstrated that retentive force is influenced by both the contact surface area between the cup-yoke and keeper, as well as the disk-yoke keeper [14]. Magnetic attachments are available in both circular and oval shapes. The magnetic circuit maybe cup-yoke or sandwich type. In a subsequent study [16], the retentive forces of cup-yoke type and sandwich type oval-shaped dental magnetic attachments in different horizontal positions were measured then the relationship between retentive force and horizontal displacement investigated. The results established that the decline in retentive force associated with horizontal movement of cup-yoke type of magnetic attachments along the major axis also occurred with movement along minor axis [16]. Analysis using mathematical formulas showed that; retentive force of cup-yoke type is influenced by contact surface areas of both disk-yoke to keeper and cup-yoke to keeper. That observation applies to both oval and round shaped magnetic attachments. However, sandwich type of magnetic attachments revealed a sharp decrease when the center was moved along the minor axis unlike a shift along the major axis [16]. Only the contact surface area of yoke to keeper influenced the retentive force when the center shifted along the major axis. The impact of the consequent change from closed to open magnetic circuit is an additional factor that affects retentive force in scenarios of displacement along the minor axis. It was determined that the retentive force pattern displayed by sandwich type of magnetic attachments varies based on the direction of movement.

Although a single dental magnetic attachment can be used in a denture; many set ups utilize multiple pieces [5, 6, 7]. When the magnetic assembly is shifted horizontally from the keeper in a setup that involves multiple oval shaped sandwich type of magnetic attachment, the retentive force is influenced by the set-up angle between any pair of magnetic attachments. There is a possibility a set-up angle exists that may counter the loss in retentive force that is associated with horizontal displacement. In this study, two oval sandwich type magnetic attachments were set in various angulations, and the pattern of retentive force against the horizontal displacement investigated.

2. Materials and methods

2.1. Set-up angulation of dental magnetic attachments

Oval sandwich type of dental magnetic attachments (Magfit EX600W, Aichi Steel Corporation, Aichi, Japan) with 3.8 mm major axis and 2.8 mm minor axis were used. The sample magnetic attachment used in this study is shown in Figure 1.

A pair of magnetic attachments was fixed 25 mm apart on the same plane as the measuring device table shown in Figure 2. First, the horizontal axis (X-axis) and vertical axis (Y-axis) were determined as the direction of movement or displacement in this study. Next, the magnetic attachments were fixed in 4 different fashions: (a) the major axis of both

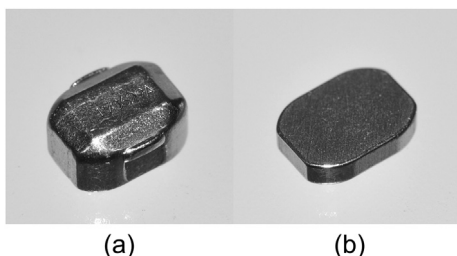


Figure 1. Dental magnetic attachment: (a) magnetic assembly, (b) keeper.

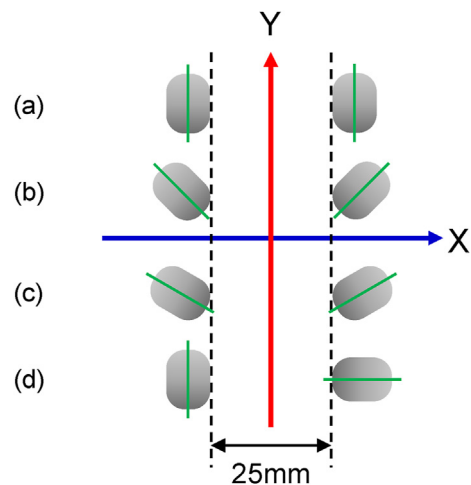


Figure 2. Set-up direction of pairs of dental magnetic attachments: (a) 0°–0°, (b) 45°–45°, (c) 60°–60°, (d) 0°–90°.

oval magnetic attachments parallel to the Y-axis (herein referred to as [0°–0°]), (b) angle formed by the major axis of each magnetic attachment to the Y-axis was 45° (herein referred to as [45°–45°]), (c) angle formed by the major axis of each magnetic attachments which were symmetrical to Y-axis was 60° (herein referred to as [60°–60°]) (d) major axis of one magnetic attachment was parallel to the Y-axis whereas the other was orthogonal to Y-axis (herein referred to as [0°–90°]).

The set up used to investigate the influence of distance between magnetic attachments on retentive force involved a pair of magnetic attachments set in [0°–0°] position and 5, 10 or 25 mm apart. The magnetic assemblies were arranged with their like or unlike poles facing each other so as to measure the repulsive and attractive forces respectively, as shown in Figure 3.

2.2. Measurement of retentive force

A measuring device that matches ISO 13017 [17] was connected to a digital force gauge (ZPS, Imada, Aichi, Japan). Retentive forces of magnetic attachments in various positions wherein the center of the magnetic assembly and that of the keeper were shifted horizontally (horizontal displacement) along the X-axis or Y-axis direction at intervals of 100 μm and at crosshead speed of 2 mm/min were measured (n = 3). The data obtained were analyzed with SPSS software version 28 using one-way ANOVA and Tukey's HSD test at a significance level of α = 0.05.

3. Results

3.1. Retentive force against the horizontal displacement

When mating surfaces of each of the two pairs of magnetic assembly and keeper were congruently matched, the retentive forces measured ranged between 9.9–10.0 N for the different set-ups. The retentive forces when two pairs were used were double that of one pair. Retentive forces decreased as the horizontal displacement increased. The decrease was

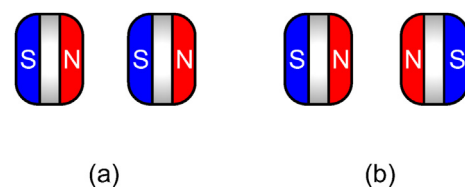


Figure 3. Poles facing each other of pair of magnetic assemblies: (a) Attractive force, (b) Repulsive force.

not linear and had several inflection points. The decline pattern in retentive force was different across the various set-up positions as explained below.

(a) 0°–0°

The relationship between the retentive force and the horizontal displacement when the magnets are set in 0°–0° is shown in Figure 4a. Initially as the magnets were moved along the X-axis direction, the retentive forces showed a steep linear decrease to 1.0 mm before stabilizing at around 2 mm of displacement then decreasing gradually. Throughout the period of horizontal displacement along the Y-axis direction, the forces from 1.5 to 2.5 mm of displacement, gradually decreased in a linear fashion.

(b) 45°–45°

The relationship between retentive force for set ups at 45°–45° and horizontal displacement are shown in Figure 4b. When the magnetic attachment was moved along X-axis direction, the retentive forces measured did match those of movement along Y-axis direction. Initially, the retentive force decreased sharply in a linear fashion up to 1.5 mm of displacement then transitioned to moderate.

(c) 60°–60°

The relationship of retentive force to horizontal displacement for the 60°–60° set up is shown in Figure 4c. The decrease associated with shift along Y-axis was greater than that of X-axis. The curve of displacement along the X-axis; initially showed a steep linear decrease in retentive forces up to 2.0 mm of displacement then transitioned to moderate. Displacement along Y-axis demonstrated an initial steep decline in forces up to 1.2 mm displacement followed by a plateau phase at around 2.2 mm, then a moderate decrease.

(d) 0°–90°

The relationship between the retentive force of a set up in the 0°–90° and horizontal displacement is shown in Figure 4d. The curve of retentive forces measured during the shift along X-axis direction matched that of Y-axis. Up to 1.0 mm of displacement; the decrease in retentive forces was steep before changing into gradual descent.

3.2. Influence of distance between magnetic attachments and retentive forces

When the magnetic assemblies were set in 0°–0° position and close to each other leaving a distance of 17 mm or less the attractive force between the two was very strong causing movement. Retentive forces against the horizontal displacement for magnetic attachments set at various distances are shown in Figure 5. Intermagnetic attachment distance of 10 mm and less yielded retentive forces equal to that of 25 mm along the same direction of displacement. Furthermore, there was no difference in retentive force measured against the displacement for set ups done in attraction or repulsion state of the magnetic pair.

4. Discussion

4.1. Independence of retentive force of each magnetic attachment

The retentive force profile against horizontal displacement of two magnetic attachments in 0°–0° (Figure 4a) was double that of a single magnetic attachment. In the case of 0°–90° as shown in Figure 2d; when the attachments are moved along the X-axis direction, the attachment on the left moves along its minor axis whereas the right one is moves along its major axis. Conversely, when the attachments are moved along the Y-axis direction, the left attachment is moved along its major axis whereas the right one is moved along its minor axis. Therefore, the curve of retentive forces measured during the shift along X-axis direction matches that of Y-axis, as shown in Figure 4d. Moreover, the profile of the two magnetic attachments at 0°–90° (Figure 4d) was equal to that of single magnetic attachment moved along its major axis combined with a single one along its minor axis. The results demonstrated that the retentive force of any two magnetic attachments is determined by the sum of the retention forces of the two separate independent magnetic attachments.

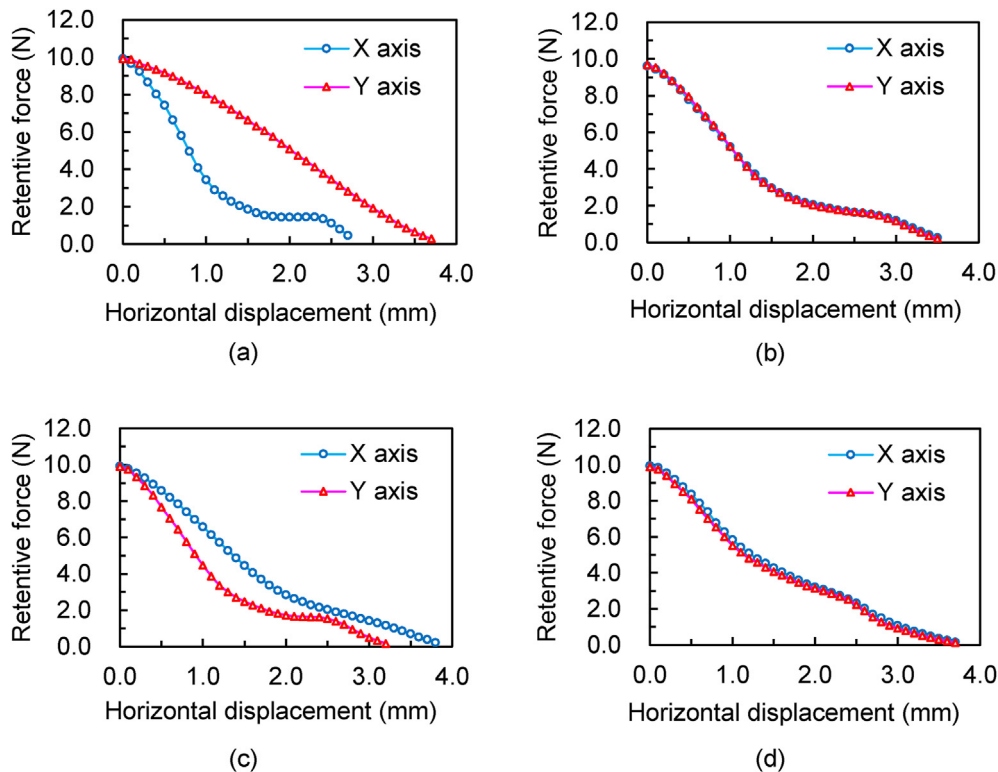


Figure 4. Retentive force of pairs of magnetic attachments against the horizontal displacement: (a) 0°–0°, (b) 45°–45°, (c) 60°–60°, (d) 0°–90°.

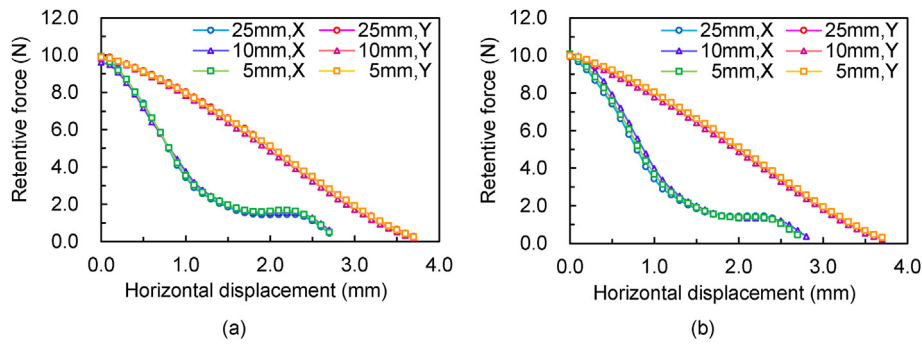


Figure 5. Distance between magnetic attachments, and their retentive force: (a) Attractive force, (b) Repulsive force.

4.2. Influence of the angle formed between the major axis and direction of movement on retentive force during horizontal displacement

In the case of 45°–45° as shown in Figure 2b; when the attachments are moved along the X-axis direction, the angle formed between the direction of movement and the major axis of both attachments is 45°. In the same way; when the attachments are moved along the Y-axis direction, the angle formed between the direction of movement and the major axis of both attachments is also 45°. Therefore, the curve of retentive forces measured during the shift along X-axis direction matches that of Y-axis, as shown in Figure 4b. The findings imply that the angle formed between the major axis and direction of movement characterizes the loss in the retentive force encountered during horizontal displacement. Therefore, the case of 60°–60° as shown in Figure 2c, which involves horizontal displacement along Y-axis direction can be termed as change in the retentive force of two magnetic attachments with an angle of 60° between the direction of movement and the major axis. Similarly, the profile of horizontal displacement along X-axis direction can be termed as change in the retentive force of two magnetic attachments with an angle of 30° between the direction of movement and the major axis.

Based on the results of conditions 0°–0°, 45°–45° and 60°–60°; the relationship of retentive force to horizontal displacement is summarized by the angle formed between the major axis and direction of movement as is shown in Figure 6. These results indicate that the decrease in retentive forces associated with horizontal displacement can be suppressed if the angle formed between the major axis and direction of movement is as small as possible. The 0°–0° set up as shown in Figure 2a shows the greatest resistance to the loss in retentive force against the horizontal displacement along Y-axis direction but not along X axis direction. The angle at which loss of retentive force is suppressed for both the X-axis and Y-axis is 45°. In other words, when the major axis of a pair of magnetic attachments forms a right angle as shown in Figure 2b and d; the loss in retentive forces which occurs with the formation of a small horizontal gap is essentially suppressed.

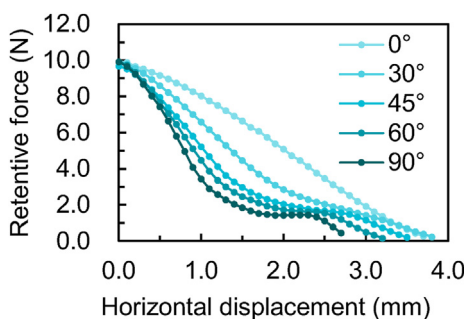


Figure 6. Retentive force of pairs of magnetic attachments against the horizontal displacement at the angle between the major axis and direction of movement.

A pair of magnets set up so that their major axes are at right angles like Figure 2d were horizontally moved slightly (0.5 mm) in various directions and retentive forces observed. As shown in Figure 7a, displacement along + X-axis direction is assigned 0° whereas that of Y-axis direction is assigned 90°. As previously mentioned, the retentive force of a pair of magnetic attachments is equal to the sum of the retentive forces of each independent magnetic attachment. For example, the retentive force of the pair of attachments as set up in Figure 2d when moving in the direction of 30° shown in Figure 7a can be calculated using the data for the left attachment in which the angle between the direction of movement and the major axis is 60° combined with data for the right attachment forming an angle of 30°. For a pair of magnetic attachments whose major axes form a right angle (set-up condition 0°–90°), the retentive forces at 0.5 mm displacement in the various directions were calculated from obtained data and the result shown in Figure 7b. All the retentive forces were greater than 8.0 N, although the retentive force of set up condition 0°–0° at 0.5 mm displacement in X-axis direction was about 7.5 N. This figure suggests that when the angle formed between the major axes of a pair of magnetic attachments is right angle; there is no direction of movement of displacement in which the retentive force is greatly compromised. Since the oval shaped magnetic attachments are point-symmetrical; the retentive force when horizontal displacement is in the direction of 180°–360° is a repetition of 0°–180°. Therefore, it can be concluded that the 90° set up is the one that maximally resists loss of retentive force with displacement in any direction.

Horizontal displacement along the major axis direction resists the loss in retentive forces compared to displacement along minor axis direction. Therefore, a pair of magnetic attachments set at right angle offers greatest resistance to loss of retentive forces with horizontal displacement as the effect of the more resistant direction compensates for the weaker one. Even with increase in the number of magnetic attachments used, the most efficient and predictable way of suppressing the decrease in retentive force is through arrangement of attachments in directions resistant to the loss in retentive force. The ideal angle between multiple dental magnetic attachments that suppresses the decrease in retentive forces that occurs due to the presence of a small horizontal gap can be predicted using Eq. (2). Ideal angle for two attachments is 90° whereas for three attachments is 60°.

$$\text{Ideal angle} = 180^\circ \div \text{number of magnetic attachment} \quad (2)$$

An illustration of a clinical scenario that involves two keepers placed at the ideal angle is shown in Figure 8.

4.3. Influence of distance between magnetic attachments on the retentive force

Magnetic assemblies set up in parallel at a distance less than 17 mm attracted each other and moved. There was no difference in the retentive force behavior of attachments set at 25 mm and less than 10 mm. An intermagnetic assembly distance of 25 mm which ensured the

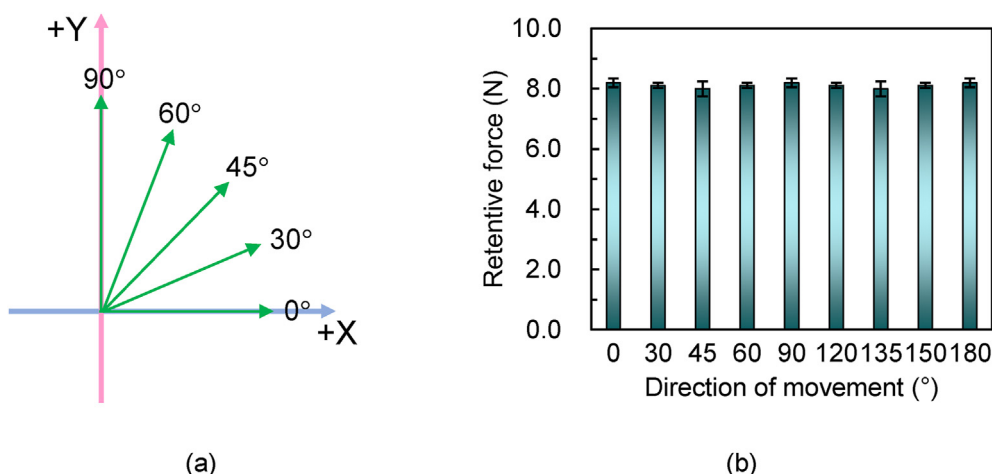


Figure 7. The retentive forces of set-up condition 0°–90° at 0.5 mm of horizontal displacement in the various directions: (a) Direction of movement, (b) Retentive force against direction of movement.

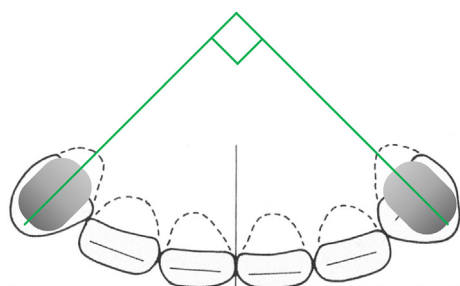


Figure 8. An example of a clinical application showing two keepers mounted on teeth at the ideal angle.

attachments remained in a detached state was maintained across all set ups done to further investigate the influence direction of major axis has on retentive forces upon displacement. There was also no difference in retentive force behavior for set ups done in attractive or repulsive fashion. This is because a closed magnetic circuit is complete when a magnetic assembly matches with keeper causing very minimal magnetic flux leakage. However, as the magnetic assembly separates from the keeper, the closed magnetic circuit transforms to an open magnetic one leading to a net attraction or repulsion effect. This phenomenon was applied in a clinical scenario. If a denture inserted in a mouth has its magnetic attachment in contact with the keeper, there is no magnetic force between one magnetic assembly and the other. However, if the denture is outside the mouth and the magnetic attachment is separate from the keeper; there is a magnetic force between the magnetic assemblies. As a result, a weak force is constantly active within the magnetic assembly. Creep, the tendency of a solid material to deform permanently under the influence of persistent stresses, can occur in polymers such as acrylic resin used to make denture base. The position and inclination of magnetic assemblies embedded in the denture base may undergo changes as a result of creep. It is therefore important when using two or more sandwich type of magnetic attachments to consider the intermagnetic distance.

4.4. Design considerations when using oval magnetic attachments in a denture

Oval magnetic attachments are fixed on natural abutment teeth to act as root copings. The keeper on the root coping is mounted with its plane parallel to the occlusal plane. If multiple abutments and root copings are utilized; the plane of both keepers should be parallel to the occlusal plane. Parallelism of the keepers to the occlusal plane is a requirement even if the

longitudinal axes of the abutment teeth are not parallel and the placement heights of the keepers (horizontal planes) are different. This study used oval magnetic attachments fixed on the same plane. Therefore, the results are relevant and applicable in clinical scenarios related to design and incorporation of retentive magnetic attachments in prosthesis like overdentures. This study revealed that the loss in retentive forces behavior which corresponds to the occurrence of a horizontal gap changes based on set up directions of sandwich type of oval magnetic attachments. Only round magnetic attachments are fixed on implant abutments. Oval magnetic attachments, which were used in this study, are applied onto natural abutment teeth. The clinical processes involve cementation of a root coping equipped with a keeper to an abutment tooth then mounting of a magnetic assembly onto the denture base in accordance to the keeper's position. It is the design of a root coping equipped with a keeper that determines the position of the magnetic attachment. The root surface of a natural tooth is generally small and the angle of inclination or torsion of the root difficult to change. Although there are limitations when designing a root coping equipped with a keeper, one should consider the set-up direction of keeper as much as possible. The ideal set-up angle to suppress the loss in retentive forces against any horizontal displacement in all directions given by Eq. (2) has exceptions. For example, the direction in which a horizontal displacement would take place can easily be predicted from factors such as: the form of residual ridge, classification of partially edentulous arches, and occlusal relationship. By designing all the major axes of keepers approaching the direction of horizontal displacement, the loss in retentive forces can be suppressed.

5. Conclusion

In scenarios where multiple magnetic attachments are to be used, the keeper's set-up angle should be considered in order to suppress the loss of retentive force against minor axis horizontal displacement. From this study; a practical, ideal set-up angle between a pair of dental magnetic attachments is 90°. Additionally, if the distance between the magnetic attachments is too small, the position and inclination of the magnetic assemblies in a denture base may change although it has minimal impact on the retentive force.

Declarations

Author contribution statement

Masatoshi TAKAHASHI: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Hirofumi YAMAGUCHI: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Yukyo TAKADA: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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