In Vivo Evaluation of the Effect of Magnet Resilient-Cushioning on Retention of Implant-Magnet-Retained Mandibular Overdenture

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Abstract: Optimizing the retention of overdenture without undue mechanical stresses or biological burden on the supporting and relevant structures is a noteworthy objective. **Purpose:** The present study aimed to investigate the effect of incorporating a resilient matrix, between a two-implant retained overdenture and its retaining magnets, on retention. **Materials and methods:** Mandibular complete dentures of 12 subjects were converted into two-implant supported overdentures. Retention of these overdentures was measured intra-orally without magnets. Next the magnets were cushioned with resilient liner and affixed into the denture, and retention was measured again. Afterwards the resilient liner was removed and the magnets repositioned and affixed with auto-polymerizing resin in the conventional way, and retention was measured for the third time. **Results: Results:** The average and standard deviation of denture retention was 68.83 ± 8.65 g for the plain denture, 443.83 ± 29.75 g for the denture with cushioned magnets and 308.33 ±15.14 g for the denture with conventional magnets. The retention of the dentures with resilient-cushion magnets was significantly higher than those with regular magnets; $p< 0.05$. **Conclusions:** Incorporating a resilient matrix between the magnets and the overdenture increased denture retention more than the non-cushioned magnets.

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Key words: Magnetic attachment; improving retention; resilient encapsulation; second magnet; keeper; samarium-cobalt; neodymium-iron-boron; ferromagnetic.

1.Introduction

Magnetic attachments have been recognized as a means of retention for overdenture.[1] The system consists of two components; the magnet which is inserted into the intaglio of the denture, and the keeper which is secured to the implant or natural tooth. Reduced lateral stresses on the implants is one of the advantages of magnetic attachments[2,3] which makes them a treatment preference for immediate loading; however, the retentive force may be compromised.[4] Eliminating the need for strictly paralleled or splinted implants or stern path of insertion of the denture, patients expediency and the ease in replacement and maintenance are added benefits that will also contribute to lowered stresses transferred to the implants.[1,2,5,6]

In spite of these virtues and the ongoing improvements, some queries are still awaiting answers. The attraction force and its longevity have been improved by introducing the rare earth magnets; samarium-cobalt (Sm-Co) and neodymium-iron-boron (Nd-Fe-B). Their attraction force per unit volume is stronger than old magnets, yet the total force is proportional to total size; volume and magnet-keeper interfacial surface area. This may explain why some manufacturers have embedded second magnets inside the keepers, but since they are permanently placed in the mouth, the oral tissues are continuously exposed to magnetic field.[7] Compliance with the specifications set by World Health Organization and the effect on magnetic resonance imaging must be addressed.[1,8] Moreover, second-magnet keepers are larger in size compared to the plane ferromagnetic-alloy keepers.

Enclosing the keeper in titanium casing is an improvement that will prevent implant corrosion;[9-11] however, the attraction force will be reduced.

In clinical practice, some limitations may affect choosing a magnetic attachment. The diameter of the implant or the abutment tooth will dictate the size of the keeper and in turn, the size of the magnet and the attraction force. A narrower implant will result in lesser retention. Increasing the diameter of the magnet beyond that of the keeper will lead to flux leakage and propagation into surrounding tissues and loss of the attraction force.[12] On the other hand; increasing the thickness of the magnet will encroach upon the inter-arch space and compromise aesthetics. Eventually, increasing the attraction force by a reasonable size of attachment, without harming the supporting or the surrounding tissues is more desirable.

Incorporating resilient substance between the denture and the attachments is known to control the loads transmitted to the infrastructure; however it is common with mechanical types[13-17] and less common with magnetic types.[18] The effect on retentive aptitude has not been investigated. However, the role of the resilient matrix is understood; it is to absorb part of the forces acting on them. It can then be postulated that, forces coming from different directions including tissue-away (vertical dislodgement) will also be dampened, and hence, extra forces will be needed to unseat the denture. In other words, denture retention will be increased.

The aim of this work was to investigate the effect of incorporating a resilient matrix between a two-implant retained overdenture and its retaining magnets, on retention.

2.Materials and Methods

From the patients who received their complete dentures at the University Hospital, Faculty of Oral and Dental Medicine and Surgery, Nahda University in Benisuef (NUB), 12 patients were selected based on their ridge size; to accommodate two 4.8 x 10 mm implants (Straumann Manufacturing, Inc., California, USA) in the intra-foraminal region. This requirement was assessed clinically and with the aid of the radiographs. To eliminate the biases that may be relevant to gender, the patients were equally distributed according to gender (6 males and 6 females). Their ages ranged between 53 and 67 years, with a mean of 59 ± 2.37. The study was approved by the ethics committee of the participating hospital. The patients included in this study were informed of the research nature of the work, and their written informed consents were obtained.

From each denture, transparent duplicate was obtained and used as a surgical template. The conventional protocol of submerged implant fixation was applied. After 6 months, the second stage surgery was performed, 3 mm, straight-walled healing abutments with regular neck (Straumann Manufacturing, Inc., California, USA)) were installed.

Measurements of the retention and the necessary modifications were carried out two weeks after installation of the healing abutments. Retention was measured with a calibrated digital force gauge (Extech 475044, Extech instruments, FLIR commercial systems, Nashua, NH, USA). A rigid extension arm was adapted for this study. It was connected to the sensing head, at right angle. The length of the arm allowed it to reach the center of the denture intraorally (figure 1 and 2). Its passivity was verified by measuring known mass suspended at the head of the sensor and then at different points on the arm, one measurement at a time. Since the same readings were obtained every time, it was confirmed that, the length of extension arm would not influence the measurements.

The force gauge was attached to the movable head of a test stand. The force gauge has two readings options; peak or continuous. The "peak" option was selected, as it means holding on the maximum value encountered.

Figure 1.The denture suspended, in a zero tilt, to the rigid extension arm which is attached at right angle to the sensing head.

Prior to retention measurements, the center of the denture mass was determined. To do so, 3 wire loops were bonded to the denture with resin bonding agent (GC Metal Primer II GC Corp., Tokyo, Japan); one loop in the midline and one distal to each of the last molars. A yarn with identifiable color was ligated in each loop, and the 3 yarns passed together through a controller circlet, then they were grouped as one master cord. The controller had the options to be relaxed or locked as required to allow sliding or capturing any of the yarns upon demand, thus allowing changing the tilt of the denture. The patient was seated with the head slightly tilted backward until the occlusal plane of the mandibular denture was aligned parallel to the horizontal plane. This position was confirmed with the aid of a spirit (bubble) level and the cephalostat and was identified by marking the respective position of the Nasion pointer on the patient's forehead and maintained by supporting the patient's head at this position (Figure 2).

To perform the measuring, the denture was allowed 10-minute intraoral tissue adaptation. The master cord was knotted to the extension arm. The force gauge was reset to zero before each measurement. The force gauge was allowed to travel vertically with a speed of 5 mm/min[12] until the denture was raised from the ridge and the reading held unchanging which indicated the maximum – peak force- retention. The readings were recorded in gram (g). Measurements were carried out 10 times with 3-minute recovery intervals,[19] and the average was recorded.

Figure 2. The length of the extension arm allowed it to reach the center of the denture intraorally. Note that, the occlusal plane of mandibular denture is aligned parallel to the horizontal plane.

All the measurements were performed in the same sitting and with same procedure. The only difference was in the retentive means of the denture. Three categories of retention means could be sequentially identified; 1) denture without the magnets, 2) denture with cushioned magnets and 3) denture with plain (non-cushioned) magnets. This sequence was dictated by the strategy to deliver the overdenture to the patients in its conservative form i.e. with the plain magnets conventionally set with auto polymerizing resin rather than with the new modification.

1. **Measuring retention of denture without magnets**

This category of measurement took place before removal of the healing abutments. The original denture was relieved in the locations corresponding to these abutments. Thus the only retentive means was the denture per se.

2. **Measuring retention of denture with the cushioned magnets**

After measuring retention of the denture without magnets, the healing abutments were replaced with the impression copings. Pick-up Impression was taken, poured into stone cast, and the magnetic keepers; 4.4 mm diameter and 3.5 mm height (Maxi Magnet keeper, Technovent, UK) were attached to the implant analogues in the obtained cast.

Preparation of the magnet cushions (Figure 3).

Magnets with 4.3 mm diameter and 3 mm height (Titanmagnetics, Steco System Technic, GmbH & Co., Hamburg, Germany) were used. The surfaces of the magnets, except the interacting surface, were prepared to secure their anchor with the soft liner They were primed (GC Metal Primer II GC Corp., Tokyo, Japan) and coated with 1 mm auto polymerizing resin (GC Unifast III GC Corp., Tokyo, Japan). The thickness of the coating was controlled by a plastic housing that was prepared from a plastic pipette of 1.5 mm wall thickness, and of an inner diameter 1 mm wider than the magnet. The inner surface of this housing was treated with release agent (A-501 Zinc Stearate, Factor II Inc., Lakeside, AZ., USA). The top of the housing was closed with pink wax. This housing amounted for a spacer that would be replaced by soft liner (figure 3 a). These magnetic assemblages were oriented onto the keepers, on the cast, and then treated with the release agent. Tunnels were drilled in the denture corresponding to -and slightly wider than- these assemblages. The tunnels were filled with auto polymerizing resin (Rapid Repair, Dentsply Limited, UK), and the assemblages were then captured into them before setting of the resin. The tunnels were thus relined with auto polymerizing resin, and the assemblage fit accurately into them (Figure 3 b). The purpose was to standardize the space that will be occupied by the soft liner. The keepers were transferred from the cast to the implants intraorally. The coated magnets were separated from the assemblages and reoriented onto these keepers. Access openings were drilled in the denture corresponding to magnets locations to allow extrusion of excess soft liner later on. The denture was cleaned, and the receptacle tunnels and the acrylic coating of the magnets were treated with the adhesive supplied with the soft liner (Mucopren soft, Kettenbach GmbH & Co. KG, Eschenburg, Germany). The receptacles were filled with the soft liner, the denture was seated in the patient mouth, and excess material was trimmed. In compliance with the instructions of the soft liner's manufacturer, the denture was immersed in a 50 ^{o}C water bath for 30 minutes to complete the setting. The integrity of the denture was then restored with auto polymerizing resin (Figure 3 c). After setting, retention was measured with the previously described method.

The tunnels were reopened, the cushioned magnets removed, and the resilient liners debrided carefully. The magnets were cleaned, returned to the keepers intraorally and picked with auto-polymerizing resin. The integrity of the denture was restored with this resin, finished and polished, and then retention was measured again.

Statistical analysis:

For each of the 12 dentures, 3 values were obtained; one value corresponding to each of the 3 retention mean(s). These data were analyzed using the Statistical Package for Social Sciences (SPSS for Windows, versions 13.0.1., Chicago, IL., USA). Data were expressed as mean ± standard deviation (SD). Comparison between the retention forces of the three regimens was performed using Repeated Measure Analysis Of Variance (ANOVA) followed by post hoc Bonferroni testing to detect the least significant difference (LSD) within the group. Significance was determined at $P< 0.05$.

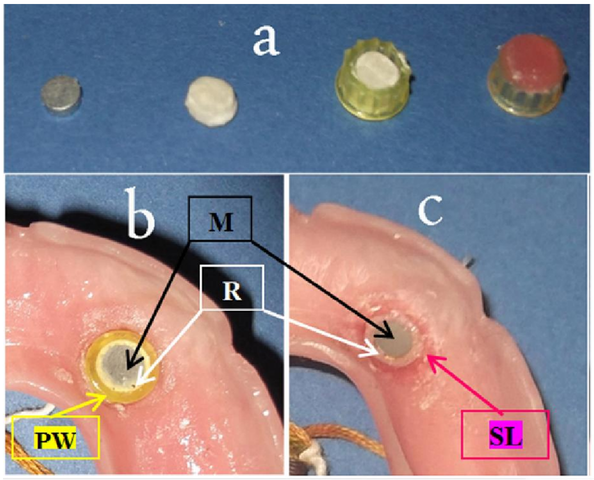

Figure 3. a) Preparations of the magnet from right to left: plain magnet coated with auto polymerizing resin followed by encapsulation into the plastic housing which is then closed with pink wax. b) Magnetic assemblage precisely fit into the denture. c) The magnet secured in the denture with the soft liner. M: magnet, R: resin, PW: plastic washer (housing) and SL: soft liner.

3.Results

The resulting retentive forces of each denture of each of the three categories are presented in table 1 and are plotted in figure. The average and standard deviation of retention of the non-magnetic, cushioned-magnetic and conventional magnetic retained overdentures were 68.83 ± 8.65, 443.83 ± 29.75 and 308.33 ±15.14 g respectively. Denture retention was statistically significant higher in both categories of dentures with magnetic attachments compared to plain denture ($p < 0.05$). The retention of the dentures with modified (resilient encapsulated) magnets was statistically significant higher than those with conventionally set magnets ($p < 0.05$).

Table 1. Data results, mean and standard deviation of retention forces (in gram) in the categories under the study.

#	1	2	3	4	5	6	7	8	9	10	11	12	Mean and ±SD
C1	53	67	73	77	64	59	80	69	67	76	80	61	**68.83 ± 8.65**
C2	517	422	432	419	424	437	473	463	418	462	436	423	**443.83 ± 29.75*Ŧ**
C3	347	294	305	298	294	302	323	310	301	319	307	300	**308.33 ± 15.14***

C1 = Dentures without magnets. C2 = Dentures with cushioned-magnets.
C3 = Dentures with plane (conventional) magnets. * = $P < 0.05$ in comparison to C1. Ŧ = $P < 0.05$ in comparison to C2.

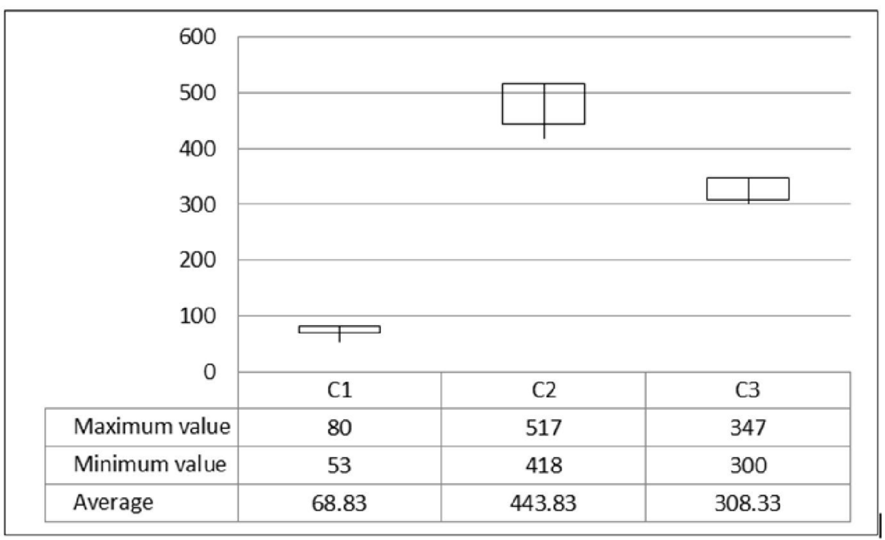

Figure 4. Diagrammatic representation of the data results; maximum, minimum, and average of retention forces (in gram) in the categories under the study.

4.Discussion

Denture retention increased with the cushioned magnets more than the non-cushioned (plain) magnets. This can be explained by the effect of the resilient liner, as it has the ability to absorb part of the forces falling on it. This included tissue-away (vertical dislodgement) forces, and hence, extra forces were needed to unseat the denture.

The retention forces would probably vary if the number of implants was increased. However, two-implant retained overdenture was investigated because it was considered as the standard of treatment of edentulous patients due to its cost effectiveness and as nearly efficiency as four-implant retained overdenture.[20,21]

This study clinically assessed the total retentive capacity of the mandibular denture and the installed attachments. This is to be differentiated from the trend of measuring displacement under masticatory-like forces. Furthermore, although improving retention of mandibular denture has always been a concern because of its compromised foundation compared to maxillary dentures, the reported clinical assessment is less. *In-vitro* studies of both dentures are abundant while the in-vivo is limited to maxillary dentures. For these reasons, no comparable data results are available in literature. The scarceness of reported clinical assessment may be due to some technical difficulties; however, this work attempted to approach them. Dealing with a mandibular denture, which is a horse-shoe shape, is not as straightforward as with maxillary denture and requires employing sound principles of physics.[22-23] To elevate a body in a perpendicular direction from its seating position, multiple loads with specific angulations should be applied at specific points; or alternatively, a single vertical load should be applied at a certain point known as the center of the mass (barycenter). It is the point around which, the distribution of mass of a body is balanced. It has to be differentiated from the geometric center (centroid). These two points will coincide in case of a single rigid body with uniform density; maxillary denture is an example. On the other hand, an open-shaped object will have its barycenter located outside its physical boundaries and is usually determined experimentally. The mandibular denture is an example. Here, the barycenter is the point (controller circlet in this study) from which, three loads (the three stretched yarns) originate and act at three different points (the three wire loops) of the denture causing its balanced lifting. As stated above, the sum of these loads is a vertical dislodging force. Therefore, sustainable stretching of the yarns until the peak force was reached would be the sign of successful measurement and vice versa; curling of one or more of these yarns would be a warning that there had been a deviation from that vertical relation due to tilting of the patient's head, and accordingly, it must be corrected.

Different values of retention forces could have ensued if the original magnetic systems were used as such rather than matching between their components. The reason of these choices; however, was to optimize retention meanwhile minimizing the bulk and the vulnerability of the supporting structures in clinical application. Closed circuit magnet and plain keeper – keepers without embedded magnets- were selected in order to retain the magnetic field within the attachment components. A Samarium cobalt (Sm-Co) magnet was selected based on the manufacturer's claim that it could withstand steam sterilization whereas Neodymium-iron-boron (Nd-Fe-B) magnets would demagnetize in temperature around 100 degree Celsius.[24] Both components are manufactured with titanium shield and laser welding to preserve the integrity of the implants against possible pitting crevice corrosion.[9-11] The keeper size was compatible with the other components (implant and magnet). These requirements were not available consolidated in a solitary magnetic system, therefore matching was made.

A similar problem may be encountered in daily clinical practice. Some manufacturers produce implants only, others produce implants and their corresponding magnetic attachments while others produce magnetic attachments compatible with only certain sizes of certain implants. Over and above, none of the existing magnetic attachments hold a resilient housing. The unavailability of these requirements in magnetic attachments may deter certain treatment modalities. If, for example, a two-implant-retained overdenture is indicated, and the clinical situation reveals difficulty in obtaining parallelism between the implants, a magnetic attachment -preferably with resilient element- will be top choice, but because they are not easily available, the available system will dictate use of a certain implant system or even skip this option. In conditions of limited amount of investing bone the situation will be more complicated; small size implants and hence small keepers, necessitating small magnets and are of compromised retention, will be indicated. The proposed idea of this study may answer these problems. Enclosing the magnet with silicon has also the potential of favorable stress distribution.[18]

Limitations of the study:

The proposed modification has to be differentiated from those magnets which are supplied with readymade stress controller element which is, yet, made of stiff material but allows a rotational movement in some directions; (Shiner SR, Preat Corporation, CA, USA),[25] (MACSsytem SR, MACS, Tokyo, Japan) and (Magsoft, Magfit, Aichi Steel Corporation, Tokyo, Japan). In consideration with that, this study is the first clinical attempt of assessment of resilient-cushioned magnets; it would not be scrupulous to deliver the denture to the patient until this modification could be recognized by further complementary researches. The plan of this study was therefore to deliver the overdenture to the patient in its conservative form i.e. with the plain magnets, conventionally set by auto polymerizing resin, rather than with the new modification. This in turn dedicated performing the measurements in the given sequence; plain denture followed by the cushioned-magnet overdenture and finally the plain-magnets overdenture which was delivered to the patient. Some limitations were initiated by this sequence.

The first limitation was the non-blinded measurements; however, the proposed modification was not in favor of any product, the proposed resilient liner was just a representative of this group of materials, and so was the magnet. Predisposition cannot be overlooked; however, it should not be overemphasized either. To restrain the effect of such probable bias, each measurement was repeated 10 times under observation of the co-workers, and the smallest measurement unit (gram g) was selected from the options of the used force gauge (1 g ≈ 1/10 N ≈ 1/1000 Kg).

One alternative study design would be to follow this sequence of denture modifications: 1-conventional denture, 2- plain-magnet overdenture, 3-cushioned-magnet overdenture and finally 4-plain-magnet overdenture –again- that will be delivered. These repeated preparations could have not only been a burden to the patients but also put the denture in the risk of weakening. Another alternative design would be to construct multiple dentures for each patient, each denture belonging to one of those retention categories; however, this would also raise another issue of the exactness of these dentures. Another possible alternative would be to obtain two groups of patients, the first with cushioned magnet while the second with non-cushioned magnet, and this could have produced multiple variables pertinent to the factors affecting retention and put the standardization of the methodology in question. Therefore, more than one study will be always required to fill the limitations of the others.

Another apparent limitation of this study was the possibility that the retention of the magnetic attachments could have been affected by the first set of measurements (10 cycles of insertion and removal) and hence another unfairness of measurement. However, it worth mentioning that, unlike most of the mechanical types of attachments which will exhibit reduction of retention due to wear caused by friction,[26-28] magnetic attraction forces are liable to only minimal reduction of attraction forces that will be caused by wear after a minimum of 540 cycles of insertion-removal.[29-32] Based on this information, mere 10 cycles would not have negative impact on the magnetic retention force. On the contrary, another study questioned its results which revealed that, initial increased retention had resulted from fatigue test.[33] These findings outweighed the previously mentioned conservative approach; to deliver the dentures in the conventional protocols and hence the selected sequence of the measurements performed in this study.

The resilient cushion was obtained from denture soft liner which was described by the manufacturer as a long-lasting or permanent denture relining material; however, the longevity of these materials when used as a cushion between the magnet and the denture needs to be studied yet.

Future studies should contemplate these limitations. They should investigate the role of time on the total retentive force of the modified magnetic attachment on one hand and the optimum resilient material; type thickness and longevity on the other hand. Worthy mentioning that, the attraction force of the magnetic attachment per se is an inherent property and manufacturing quality just like all other types of attachments. After long term use under resilient cushioning, the alteration in the stresses transmitted to the magnet may also alter its properties - favorably or unfavorably - than if it was not cushioned.

The proposed modification is cost-effective and can be easily applied with implant and may be suggested for natural teeth as well.

Conclusions:

Within the limitations of the present study, it could be concluded that:

- Incorporating a resilient substrate between two-implant retained overdenture and the magnets improved the effect of magnetic attachments on denture retention.
- Further studies are required to assess long term performance of the proposed modification.

Clinical Implications:

Incorporating a resilient matrix between the magnets and the overdenture increases denture retention. It is cost-effective, method that can be easily applied with implant and may be suggested for natural teeth as well. Long-term data are needed to assess the longevity of this modification.

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