The Influence of Interimplant Distance and Attachment Type on the Retention Characteristics of Mandibular Overdentures on 2 Implants: Initial Retention Values

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Purpose: This in vitro study aimed to investigate the influence of *(1)* the interimplant distance and *(2)* the type of attachment on the retention of mandibular overdentures on 2 implants. ***Materials and Methods:*** Three stone casts were fabricated, each with 2 implant analogues embedded at distances of 19, 23, and 29 mm apart. Three different interchangeable mandibular overdenture attachments were secured onto the analogues: Hader bars, ball abutments, and stainless steel keepers for new generation neodymium-iron-boron magnets. In total, 45 groups of paired attachments were tested for initial vertical peak tensile load at the 3 interimplant distances. ***Results:*** Interimplant (interclip) distance played a significant role only in the retention produced by the Hader bar/red clip configuration. At 19 and 23 mm, the ball/socket attachments were statistically more retentive than the yellow clips, white clips, and magnets, but not compared to the red clips. At 29 mm, the ball abutments showed statistical superiority compared with all other attachments. Mean clinical intercanine distance for conventional full dentures was 22.88 mm. ***Conclusion:*** Interimplant distance can affect the initial retention of mandibular overdentures on 2 implants depending on the type of attachment used. For a predetermined interimplant distance, attachment performance varies greatly. *Int J Prosthodont 2006;19:507–512.*

Mandibular implant-retained and/or supported overdentures are a very reliable means of prosthetic restoration for the edentulous patient. The plethora of implant overdenture attachments used in this clinical modality has been studied for both initial and long-term fatigue retention. In vitro testing has involved individual attachments in the case of nonsplinted stud-type attachments,[1,2] testing of pairs for both splinted and nonsplinted attachments,[3–5] and assessment of multiple splinted and nonsplinted attachments.[6,7] In vivo studies of overdenture retention have also been conducted.[8–12] There seems to be a uniform consensus that bar and clip configurations have higher retention values compared with ball or magnetic attachments, although the clinical significance of this consensus is unclear. The combination of metal (titanium or gold) patrix and plastic or nylon matrix was shown both in vivo and in vitro to provide the least favorable results in initial and fatigue retention testing.[11,13]

Although the different designs of overdenture attachments have been the scope of previous investigations, the potential influence of varying interimplant distances on prosthesis retention has never been investigated. Interimplant or interclip distance is either overlooked or chosen arbitrarily in studies on paired attachment retention.

The aim of this in vitro study was to measure the initial retention values obtained by 5 pairs of commonly used implant overdenture attachments tested at 3 different interimplant and interclip distances.

Two null hypotheses were tested:

1. Interimplant and interclip distances do not influence mean initial retention of the attachments tested.
2. For a given interimplant distance, there is no difference in mean retention values for 5 different attachments used to retain a mandibular overdenture on 2 implants.

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Table 1 Attachment Types Used in the Study

Manufacturer	Attachment	Type	Material of male component	Material of female component
Metalor	MP bar/clip	Hader bar	Gold	Plastic (white)
Metalor	MP bar/clip	Hader bar	Gold	Plastic (yellow)
Metalor	MP bar/clip	Hader bar	Gold	Plastic (red)
Astra Tech	Ball abutment (cuff length 3.0 mm)	Ball/socket	Titanium	Gold
Aichi Steel	Magfit IP-AD	Magnet/keeper	AUM20 stainless steel (keeper)	NdFeB (magnet)

Fig 1 *(left)* Hader bar secured onto the implant-retaining block.

Materials and Methods

Intercanine Distance Measurement

In order to measure the intercanine distance and correlate it with the findings of the subsequent in vitro study, a pilot study was conducted. One hundred consecutive conventional complete mandibular dentures at the stage following the full try-in and before final processing were used. The dentures were fabricated at the Removable Prosthodontics Production Lab, within the Unit of Prosthodontics, University Dental Hospital of Manchester. The prostheses were set by the dental technician responsible for the completion of each case. The trial setup was positioned onto the master cast. A 70-mm-long plastic flexible ruler was positioned on the tip of the canine unilaterally, and 2 marks were made, one on the buccal aspect and the other on the lingual aspect of the cast, ensuring that the line connecting them passed through the tip of the canine. The same procedure was repeated for the other side. The distance between these 2 lines was measured at a straight line to the nearest 0.5 mm by the same operator using the same calibrated ruler, and the outcome was expressed as mm of intercanine distance at the residual ridge level. The mean intercanine distance (22.88 mm) was then rounded to the nearest mm and used as 1 of the 3 interimplant distances investigated in the second part of this in vitro study. Instead of using a minimum intercanine distance of 16 mm as measured in the pilot study, the decision was made to use a distance of 19 mm as the minimum, to allow enough space for 2 5-mm-long plastic clips to be positioned, and also for the necessary bulking at the bar/cylinder joint bilaterally. Likewise, instead of using a maximum distance of 31 mm as measured in the pilot study, a 29 mm value was used to better account for anatomic limitations such as the curvature of the mandibular arch (to allow for a straight bar to be used) and the position of the mental foramina.

Fabrication of the Implant Analogue Blocks

The second part of the study involved placing 2 implants with various attachments to record the in vitro retention. A modified implant jig was designed. To serve as the implant positioning jigs, 3 blocks of Perspex acrylic resin were drilled using a 4-mm-diameter cylindrical drill to produce 2 holes, with their centers at a distance of 19, 23, and 29 mm, respectively. Three such blocks with 2 implant analogues each were cast, one for every interimplant distance tested.

Fabrication of the Patrices of the Attachments

The 5 types of attachments used in this study are shown in Table 1.

Uni Abutments with a taper of 20 degrees and a cuff length of 3 mm (Astra Tech) were hand-torqued onto the implant analogues, and plastic burn-out cylinders (Astra Tech) with a height of 5 mm were secured onto them. Plastic Hader-type bar patterns (MP bars, Metalor) were cut and adjusted to fit between the cylinders at all 3 distances and subsequently cast in type III precious metal alloy (3 Star, Metalor). Three Hader-type bars, one for each interimplant distance, were fabricated (Fig 1).

For the prefabricated patrices, Magfit-IP-AD dome-shaped keepers (Aichi Steel) and 1-piece ball abutments with a cuff length of 3 mm were interchangeably hand-torqued onto the implant analogues for the tensile tests.

Fabrication of the Matrices of the Attachments

For the fabrication of the acrylic resin blocks carrying the 2 5-mm-long bar clips, 2 metal housings, with their corresponding space retainers, were positioned onto each bar at a distance of 1 mm from the bar/cylinder junction. Orthodontic wire 1.25 mm in diameter was used to make 2 standard size-retaining loops, 1 for each implant. Self-

Table 2 Number of Groups Formulated for All Attachment Types at All Distances Tested

	Interimplant distance		
Attachment	19 mm	23 mm	26 mm
2 Magnets	3 groups	3 groups	3 groups
2 Ball/socket	3 groups	3 groups	3 groups
1 Bar/2 white clips	3 groups	3 groups	3 groups
1 Bar/2 yellow clips	3 groups	3 groups	3 groups
1 Bar/2 red clips	3 groups	3 groups	3 groups

Fig 2 *(right)* Testing apparatus positioned on the universal tester.

cured acrylic resin (Trevalon, Dentsply) was subsequently poured into the mold to retain the clips. Altogether, 3 acrylic resin blocks, 1 for each distance, were made. The metal housings aided the accurate repositioning of the plastic clips and thus negated the fabrication of a great number of acrylic resin blocks. For the bar/clip assemblies, interimplant distance was correlated with interclip distance using the following equation:

$$X = ID - d / 2 - d / 2 - 10 - 2$$

X is the interclip distance
ID is the interimplant distance
d is the implant diameter
10 is the total length of the 2 clips (mm)
2 is the distance from the clip to the cylinders (1 mm on either side)

For the fabrication of the acrylic resin blocks carrying the metal sockets, the same procedure as with the bar clips was followed. A total of 9 blocks, 3 for each distance, were made.

For the fabrication of the blocks carrying the magnets, a different approach was selected. The keepers were secured onto the implant analogues, and a box was again formed using modeling wax. The magnets were carefully positioned onto the stone dummies of the keepers and firmly held in place with wax. Whereas frictional retention is adequate enough to preclude movement between male/female attachment components during acrylic resin block fabrication in bars/clips and ball/socket assemblies, magnetic attachments exhibit low resistance to horizontal movement. Therefore, accurate location and stabilization of the magnets on the keepers during pouring of the acrylic resin was essential. Again, 9 blocks, 3 for each distance, were fabricated. In the case of the ball attachments and magnets, interimplant distance coincides with interattachment distance.

Mounting the Blocks on the Universal Tester

Stainless steel key rings 26 mm in diameter were laser-welded onto the top portion of the loops on every block, thus providing a single point of attachment to the upper arm of the tester. A stainless steel hook was attached to the ring and to the upper arm of the tester via a stainless steel rod (Fig 2). The universal testing machine (M5, Nene Instruments) was equipped with a load cell with a range 0 to 50 N for the application of force, and the tester was connected to a PC for on-screen viewing of the results. The data were stored on the PC's hard drive for further analysis. The crosshead speed selected was 50 mm/min, as this was previously described by Sarnat[14] to approximate the speed of overdenture removal in vivo. Altogether, 45 pairs of attachments were used for this in vitro experiment (Table 2).

Each pair was positioned and removed 10 times from the corresponding male attachment–carrying block, and the resultant peak tensile load was recorded.

Statistical Analysis

Before initiating the study, a sample size calculation determined that 3 blocks in each attachment group would have 82% power to detect a difference in means between 2 groups of 16 N, assuming that the common SD is 5 N using a 2-group *t* test with a .050 2-sided significance level.

The peak tensile load produced during attachment separation was recorded in N. The obtained values were loaded into statistical analysis software (SPSS version 11.5, SPSS). The mean of the 10 measurements for tensile load were analyzed using a 1-way analysis of variance (ANOVA) Bonferroni test.

Results

The mean intercanine distance was 22.88 mm (SD = 2.73). The minimum distance was 16 mm and the maximum was 31 mm.

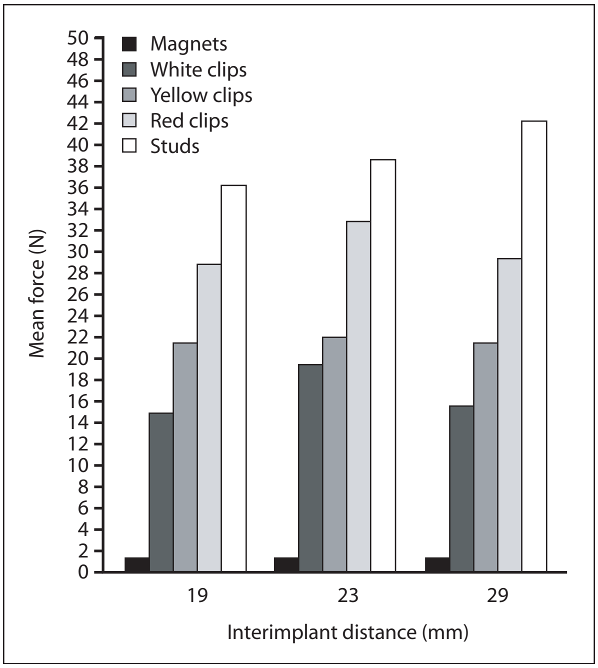

Fig 3 The mean tensile load registered for every attachment per interimplant distance.

The performances of the 5 attachment groups were analyzed and compared 2-dimensionally. Each attachment type was examined at all 3 interimplant distances for differences in retention values, and all attachments were compared regarding their retention for a given interimplant distance:

- The ball/socket attachments produced different mean retention values at interimplant distances of 19 mm (34.56 N, SD = 5.45), 23 mm (36.99 N, SD = 4.84), and 29 mm (40.44 N, SD = 2.61), but the differences were not statistically significant.
- The bar/red clip attachments produced different mean retention values at 19 mm (27.63 N, SD = 0.53), 23 mm (31.41 N, SD = 1.29), and 29 mm (28.01 N, SD = 0.95). Statistical significance was detected between 23 mm and the other 2 distances ($P = .05$).
- The bar/yellow clip attachments produced very similar mean retention values at 19 mm (20.33 N, SD = 1.14), 23 mm (20.81 N, SD = 3.3), and 29 mm (20.61 N, SD = 2.33), with no significant differences.
- The bar/white clip attachments produced mean retention values that were higher at 23 mm (18.47 N, SD = 1.04) than those at 19 mm (14.19 N, SD = 2.26) and 29 mm (14.91 N, SD = 4.29), but the difference lacked statistical significance.
- The magnets produced very low retention values at all distances: 19 mm (1.23 N, SD = 0.53), 23 mm (1.13 N, SD = 0.27), and 29 mm (1.29 N, SD = 0.85). Statistical analysis revealed no significant differences.

Comparing the retentive capabilities of the attachments for each interimplant distance revealed that the same order of retentive strength existed at all distances. The ball/socket attachments were the most retentive, followed by the bar/red clip, the bar/yellow clip, and the bar/white clip configurations. The magnets were the least retentive, at a highly significant level ($P = .000$).

At 19 mm, ANOVA revealed that the ball/socket attachments were significantly more retentive than the yellow clips ($P = .001$) and white clips ($P = .000$), but not compared to the red clips ($P = .107$). The latter were more retentive than the white clips ($P = .001$).

At 23 mm, the ball/socket attachments were statistically more retentive than the yellow clips ($P = .000$) and white clips ($P = .000$). The red clips were also statistically more retentive than the yellow clips ($P = .008$) and white clips ($P = .002$).

At 29 mm, the ball/socket attachments were statistically more retentive than the red clips ($P = .001$), yellow clips ($P = .000$), and white clips ($P = .000$). The red clips were significantly more retentive than the white clips ($P = .001$).

Figure 3 shows a visual summary of the mean tensile load registered for every attachment per interimplant distance.

Discussion

The mean intercanine distance was 22.88 mm, a value very close to the 22 mm reported in the literature for mature untreated Angle Class I dentition.[15] Proper employment of the principles of teeth setup during complete denture construction can ensure an esthetic result that closely approximates the dentate condition. Further, when complete dentures are duplicated and radiographic and surgical stents are made, the final interimplant distance can be precisely planned.

In the present study, interimplant distance played a significant role only in the retention forces produced by the bar/red clip configuration. At 23 mm, the mean retention was statistically higher than the mean values obtained at 19 mm and 29 mm:

$$R_{23} > R_{29} > R_{19}$$

R is the mean peak retentive force

Regarding the effect of interclip distance, it was found that when 2 red plastic clips (5 mm long) were positioned 7 mm apart on an MP bar connecting 2 implants 23 mm apart, the resulting tensile forces during the upward movement of the acrylic resin block have a higher mean value (36.99 N) than if the same clips were positioned either 3 or 13 mm apart. At 13 mm, the resulting direction of movement of the block produces a higher (although not statistically significant) mean retention force than that produced at 3 mm (28.01 N and 27.63 N, respectively). The initial retention values reported here for the bar/red clip assemblies at 23 mm are comparable to the results of a previous study, although the methodology varies.[4] Furthermore, in this study, the red clips seemed to stabilize by the tenth pull at 19 mm, but continued to lose retention up to the tenth pull at both 23 and 29 mm.

For the ball/socket attachments, the highest mean peak tensile force was usually at 29 mm:

$R_{29} > R_{23} > R_{19}$
R is the mean peak retentive force

Similar studies that investigate the effect of interimplant distance on ball/socket retention are lacking. Comparisons can only be made with experiments that have reported the interimplant or interattachment distance within their study protocols. For an interimplant distance of 20.75 mm, Petropoulos and Smith[16] reported consistently lower mean retentive values for titanium ball/titanium socket attachments compared to the values reported for the titanium ball/gold socket attachments in this study, regardless of the interimplant distance. The difference may be attributed to different materials showing different rates of wear, a phenomenon that has been described in the literature for both initial and fatigue retention.[17]

Similarly, regarding magnetic attachments, no in vitro or in vivo study exists designed to examine the effect that the distance between magnets has on retention. Therefore, the findings of the present study are unique concerning the correlation between interimplant distance and retention. Magnets in this trial showed consistently low retention forces compared to the other attachments. The mean peak load ranged from 1.13 to 1.29 N, with the following relationship between force and interimplant distance (not statistically significant):

$R_{29} > R_{19} > R_{23}$
R is the mean peak retentive force

The values observed in this study were almost 5 times less than those specified by the manufacturer (Aichi Steel). The SDs ranged from 0.27 to 0.85 N, which means that even the highest retention value would still be 2.5 times less than that reported by the manufacturer. In addition, the values reported by the manufacturer refer to single attachments measured under ideal laboratory conditions, whereas our values correspond to paired attachments embedded into acrylic resin blocks following the standard technical procedures that one would expect to find in a dental laboratory. These differences may have accounted for the discrepancy between the values. Lehmann and Arnim[18] determined that the minimum attraction force for a single attachment to retain a prosthesis satisfactorily was 400 g (3.92 N). Our results show that the magnets fall short of this requirement.

The neodymium-iron-boron (NdFeB) magnets are relatively recent developments and are reportedly 20% stronger per unit volume than samarium-cobalt magnets ($SmCo_5$).[19] Although the magnets in this in vitro study were a new generation of NdFeB, their retention values were at the level of those reported in the literature for older $SmCo_5$ magnets. Several authors have reported mean retention values for $SmCo_5$ magnets, ranging from 0.58 to 6.41 N.[19,20] This may be a result of the actual occlusal-gingival height of the magnets (1.4 mm). It has been shown that for rare earth magnetic alloys, size and volume play an important role in the resultant retention.

The magnetic attraction at 19 mm (mean 1.23 N) correlates well with the results reported by Petropoulos et al[3] for the arbitrarily chosen distance of 20.75 mm (mean 1.25 N). Further research is needed to optimize the retentive forces produced by the magnets and to determine the impact that the distance between magnets has on their retention profile.

The 5 attachments used in the present study had their retentive potential preset by their respective manufacturers. No effort was made before or during testing to activate or deactivate the clips or sockets, and the only effect on their retention was from the repeated tensile loading. Considering their mean SDs, it was concluded that the red clips were the most consistent, since their mean total SD was only 6% of their mean total peak load. The yellow clips were the second most consistent (10%), followed by the ball abutments (12%) and white clips (19%). The magnets exhibited the least consistency (42%), although at 23 mm, the SDs observed were only 24% of the mean peak load at this distance. When adjustable attachments are tested, a large SD can be expected.[3] Since these attachments were not adjusted by the operator, the high SDs may imply either a shortcoming in the measuring equipment and technique or a variation in the manufacturing process. This may be especially true for the magnets. On the other hand, if SDs are small, it can be assumed that shortcomings of the measuring device are not responsible for the differences in retention. It is more likely that the manufacturers cannot guarantee identical retention forces.

The method of attaching the blocks to the universal tester was designed to simulate the clinical situation as closely as possible. The way in which patients are instructed to remove an overdenture is to place their thumbs against the anterior flange of the prosthesis, at the position where the implants are located, and lift the denture upwards by exerting simultaneous force with both hands. Thus, the stainless steel loops were positioned over the implants. Instead of using multiple chains to connect the loops with the universal tester, they were interconnected with a ring that allowed for balancing movements of the *S*-shaped hook to be made, thus establishing the point of load application in the middle of the interimplant distance. Other researchers have pointed out the possibility of measurement errors as a result of uncontrolled difference in the slack when 2 or more chains are used for connection to the testing machine.[3] The goal was to treat the 2 attachments as 1 system, and to study their behavior in relation to interimplant distance.

Finally, placing the implants 19, 23, or 29 mm apart did not have a significant effect on the retention provided by 4 of the 5 attachment pairs. Therefore, a possible clinical implication of this result is that clinicians can decide to place implants closer together without an adverse effect on the prosthesis' retention, assuming these 4 types of attachments are used and still have adequate interforaminal space for further placement of distal implants, in case the patient later opts to switch to an implant-supported FPD or overdenture. However, further analyses of the fatigue retention values for the attachments tested in this study are needed to verify this claim.

Conclusions

Within the limitations of this in vitro study, the following conclusions can be drawn:

- Interimplant (interclip) distance plays a significant role only in the retention forces produced by the MP bar/red clip configuration. At 23 mm (7-mm interclip distance), the mean retention value was statistically higher than the mean values obtained at 29 mm (13-mm interclip distance) and 19 mm (3-mm interclip distance). Therefore, the first null hypothesis was accepted for this type of overdenture attachment and rejected for the rest.
- For a given interimplant distance, there were statistically significant differences in the performance of the various overdenture attachments, and the relationships varied according to the interimplant distance. Therefore, the second null hypothesis was rejected.
- Ball/socket attachments were the most retentive attachment type, especially at 29 mm.
- Magnets were the least retentive attachment type.

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