Original Article

The Effect of Inter-Implant Distance on Retention and Resistance to Dislodging Forces for Mandibular Implant-Tissue-Supported Overdentures

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Abstract
Objectives: The effect of inter-implant distance on retention and resistance of implant-tissue-supported overdentures is lacking in the literature. An in vitro study was performed to evaluate this effect for mandibular implant-tissue-supported overdentures retained by two ball attachments.
Materials and Methods: An acrylic cast of an edentulous mandible was fabricated. Three pairs of implants were symmetrically placed at both sides of the midline. The inter-implant distance was 10, 25, and 35 millimeters in positions A, B and C, respectively. A framework simulating the overdenture was fabricated on the cast. Six attachment housings were placed within the overdenture. For each sample, two ball abutments were screwed onto the implant pairs and two pink nylon inserts were seated in their respective attachment housings. The samples were tested in three groups of 15 (A, B, and C). The testing machine applied tensile dislodging forces and peak loads were measured in three directions: vertical, oblique, and anterior-posterior. A one-way ANOVA followed by Tukey's HSD was used to determine groups that were significantly different. Tests were carried out at 0.05 level of significance.
Results: Peak loads for the anterior-posteriorly directed dislodging forces were significantly the highest for group C ($P<0.05$); 21.25 N±3.05 N, while there were no statistically significant differences among groups with vertically and obliquely directed forces ($P>0.05$).
Conclusion: Inter-implant distance did not affect the vertical retention and oblique resistance of mandibular implant-tissue-supported overdentures; however, it affected anterior-posterior resistance.
Key Words: Dental Implant; Overdenture; Dental Prosthesis Retention; Implant-Supported Dental Prosthesis

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INTRODUCTION

The mandibular implant-tissue-supported overdenture (MITSO) using two implants is the first choice standard of care for the edentulous mandible, especially when finances prohibit more implants to be placed [1].
Complete dentures are replaced by implant-tissue-supported overdentures by placing two implants and using attachments. Some of the information for the selection of attachments is derived from clinical experience [2,3].
The overdenture must be carefully designed to

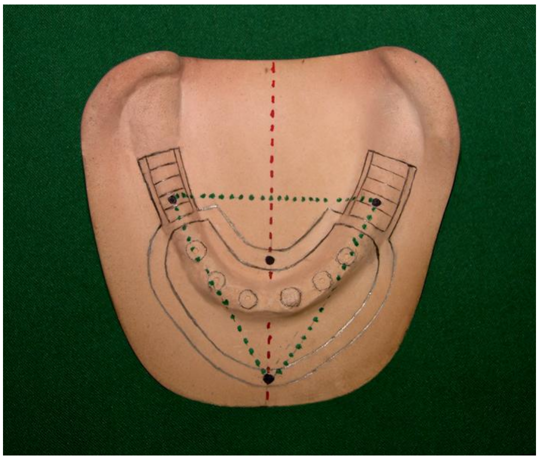

Fig 1. Design of the different parts. Locations of implants, overdenture, and force application points based on the hypothetical triangular design

achieve adequate stability, optimal form, contour, esthetics, and the patient's best comfort [4]. Stud-type attachments are the most commonly used among different types of attachments [5]. There are many factors for the selection of attachment systems including the amount of space available, maintenance requirements, load distribution to the mucosa and implants, and the level of retention and resistance desired. Retention is defined as the capacity of the prosthesis to oppose with vertical forces, while resistance is defined as the capacity to oppose with forces other than vertical forces, including oblique and anterior-posterior forces. The retention and resistance of the MITSO play significant roles in resuming function and patient satisfaction [6-8].

Retention and resistance are influenced by the type of attachment and the design [9,10]. The wear of components [11,12] and implant angulation [13] can affect the retention. Van Kampen [14], Petropoulos [5,10,15], and Tabatabaian [9] in separate studies have evaluated retention and resistance with different attachments while the implants were inserted at the symphyseal region .

When placing two implants for a MITSO, the implants are traditionally located between the mental foramina [16]; therefore, another factor that may be considered is the inter-implant distance, which is the distance between the two implants. To the best our knowledge, a few studies have evaluated the effect of inter-implant distance on retention, while the effect of this factor on resistance has not been assessed. Michelinakis [17] and Doukas [18] found that the inter-implant distance can affect the retention of MITSO depending on the type of attachment used. Alsabeeha [19] found the need for further studies on factors affecting retention for MITSOs and emphasized that these factors must be studied separately under well-controlled conditions. The impact of inter-implant distance on the retention and resistance of MITSOs is lacking in the literature.

Tokuhisa [20] has reported that ball attachment is commonly used and it optimizes load transmission while minimizing overdenture movement. Therefore, the purpose of this in vitro investigation was to assess the effect of inter-implant distance on the retention and resistance of MITSOs. The null hypothesis of this study was that the inter-implant distance would not affect the retention and resistance of a MITSO retained by two ball attachments when tensile dislodging forces were applied.

MATERIALS AND METHODS

This in vitro study was performed on 45 overdenture samples divided into three groups of 15: A, B, and C, each based on the position of implants. Each overdenture sample was tested three times to examine vertically, obliquely and anterior-posteriorly directed tensile dislodging forces. For equal distribution of forces, a hypothetical equilateral triangle with 5 cm sides was created. The three corners and the center of the triangle were used for force transmission (Figure 1).

Test cast fabrication

A mandibular acrylic cast was fabricated from a master cast belonging to an edentulous patient with a medium-sized, ovoid arch form. The undercuts were relieved and the borders were extended to match the mentioned design.

Fig 2. The framework with a special design seated on the test cast while encircling the six implants

Fig 3. Ball attachment set including three components: ball abutment (below), attachment housing (above, external part), and pink nylon insert (above, internal part)

The test cast was prepared using clear self-polymerized acrylic resin (Meliodent, Heraeus Kulzer, Senden, Germany) to simulate the mandibular arch.

Three pairs of implants with 4 mm diameter and 12 mm length (PGR4012, BioHorizons, Birmingham, Alabama, USA) were inserted on both sides of the midline symmetrically in parallel positions with inter-implant distances of 10, 25, and 35 millimeters, and at the approximate locations of laterals, canines and first premolars namely positioned as A, B and C, respectively.

In the current study, the inter-implant distance was defined as the straight distance between the centers of the paired implants.

A milling machine (Paraskope M, Bego, Bremen, Germany) was employed to ensure the same correct angulations of all implants. A cast framework, made of a chrome-cobalt alloy (Remanium GM 800+, Dentaurum, Ispringen, Germany), was constructed as a denture base on the posterior region of the ridge and a frame-like structure on the anterior area, encircling all implants.

The anterior part of the framework, where the overdenture housing would be attached, was subjected to a sandblasting unit (Korostar Plus, Bego, Bremen, Germany).

The framework had four hooks: two at the site of first molars on the denture base and the remaining two on the posterior and anterior limits of the frame-like structure (Figure 2). The four hooks were of the same height.

Overdenture housing fabrication

A prototype was fabricated over the anterior part of the framework on the test cast using light-polymerized custom tray material (Megatray, Megadenta Dentalprodukte, Radeberg, Germany). Three rectangular stop points were formed in its inferior surface. The prototype was placed in a denture duplicating flask, containing C-silicone putty material (Zetaflow Putty, Zermack, Badia Polesine, Italy). After setting of the material, the flask was opened and the prototype was taken out. Clear heat-polymerized acrylic resin (Meliodent, Heraeus Kulzer, Senden, Germany) was poured into the flask in order to prepare an overdenture housing by duplicating the prototype. The flask was submerged in warm water for 60 minutes. Finally, the overdenture housing was fabricated as such and adapted on both the framework and test cast. It was connected to the framework with clear self-polymerized acrylic resin. Thus, the framework and overdenture housing acted as a unit named overdenture.

Fig 4. Overdenture. Attachment housings with pink nylon inserts placed within the overdenture housing

Specimen preparation

The ball attachment set (BCAS, BioHorizons, Birmingham, Alabama, USA) with the three following components was used to attach the overdenture to the implants: 1. Ball abutment with 2.5 mm diameter (PGBA1, BioHorizons, Birmingham, Alabama, USA). 2. Attachment housing (BCAHT, BioHorizons, Birmingham, Alabama, USA). 3. Pink nylon insert (BCIP, BioHorizons, Birmingham, Alabama, USA) (Figure 3).

Two ball abutments were screwed onto the implants of position A and torqued to 30 Ncm with a torque wrench (300-430, BioHorizons, Birmingham, Alabama, USA). The complex of attachment housings and pink nylon inserts were placed on the ball abutments in a parallel position adjusted by a dental cast surveyor (Dental Surveyor, Krupp Medizintechnik, Essen, Germany) and fixed in their respective locations. The overdenture housing was perforated over the implant sites. After immobilization of the overdenture on the test cast, the perforations were filled with clear self-polymerized acrylic resin covering the attachment housing edges. This process was done with the same two ball abutments in positions B and C until the six attachment housings were placed within the overdenture housing (Figure 4).

The pink nylon inserts acted as the keyway, while the ball abutments acted as the key. By engaging these components, the overdenture would be retained on the test cast. The three stop points under the overdenture housing and the position of overdenture bases were the references for ensuring the correct seating of the overdenture.

The new and intact pink nylon inserts were allocated, and then were observed by a magnifying glass in order to exclude the impaired ones. For each overdenture sample, only pink nylon inserts were replaced and the other parts were the same among the samples. Obviously, the locations of ball abutments and attachment housings were predetermined relevant to the group of the sample (A, B, and C).

Testing

A universal testing machine (Zwick Z020, Zwick/Roell, Ulm, Germany) was used to apply and measure tensile dislodging forces.

A metallic S-shaped hook with 15.5 cm length was connected to the horizontal crosshead of the machine. Another hook was used to connect the first hook to the load cell, a circle steel plate with 8 cm diameter.

Four loops were designed on the inferior surface of the load cell corresponding to the hooks on the overdenture. A piece of polyester string (Polyester cord 0.407 mm2, Kian Cord, Malayer, Iran) was used for load transmission from the load cell to the overdenture attached to the test cast, while the test cast was fixed to the inferior platform of the testing machine (Figure 5). The string was passed through the corresponding hooks on the overdenture and loops on the load cell and tied at the end. To measure the peak load for the vertically directed dislodging forces, the string was passed through all hooks. To measure the peak load for the obliquely directed dislodging forces, three hooks were involved (all except one of the posterior hooks); whereas, for anterior-posteriorly directed dislodging forces only the two posterior hooks were involved.

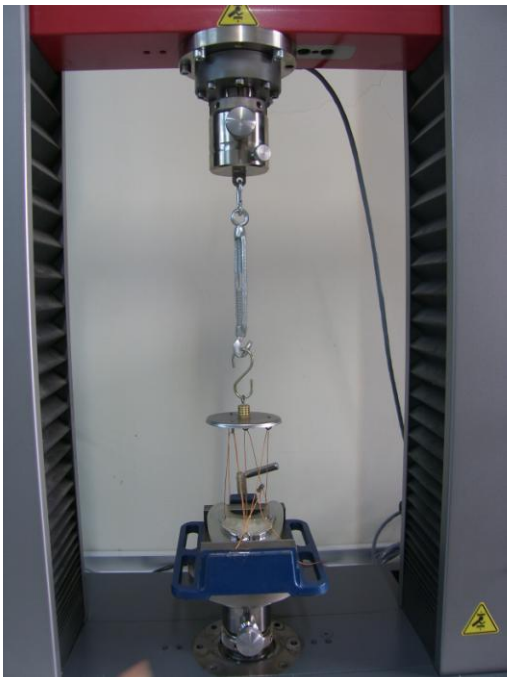

Fig 5. Zwick testing machine. Connections of the machine, load cell, overdenture, and test cast for load transmission

The crosshead speed was adjusted at 51 mm/min, which would approximate the rate of denture movement during mastication [21]. The peak load was measured and was represented with the peak point load profile curve demonstrated for each test.

Kolmogorov Smirnov test [22] indicated normal distribution of the data ($P>0.05$). Therefore, a one-way ANOVA was used to evaluate the peak loads for the vertically, obliquely and anterior-posteriorly directed dislodging forces separately for the three A, B and C groups. In addition, homogeneity of variances showed that the three groups were the same ($P>0.05$). Thus, Tukey's HSD test was used for paired comparison of the three groups. The results were reported with a 95% confidence interval.

RESULTS

The peak loads for the vertically directed dislodging forces were measured as 25.03 N±7.47 N, 22.91 N±6.23 N, and 24.50 N±5.83 N for groups A, B, and C, respectively (Figure 6).

There were no statistically significant differences among the three groups ($P>0.05$). The peak loads for the obliquely directed dislodging forces were 20.92 N±4.39 N, 18.14 N±4.85 N, and 18.76 N±6.32 N for groups A, B, and C, respectively (Figure 7).

No statistically significant differences existed among the three groups ($P>0.05$).

The peak loads for the anterior-posteriorly dislodging forces were 14.46 N±2.11 N, 14.94 N±3.83 N, and 21.25 N±3.05 N for groups A, B, and C, respectively (Figure 8). There was a statistically significant difference in this respect among the three groups ($P<0.05$). Considering $P<0.05$, Tukey's HSD test was applied for paired comparison of the three different groups.

No statistically significant difference was found between groups A and B ($P>0.05$), while the peak loads for the anterior-posteriorly dislodging forces were the highest for group C when compared to groups A and B ($P<0.05$).

DISCUSSION

Retention and resistance of MITSOs depend on various factors including attachment type and design, wear of components, and implant angulation [9-13]. Alsabeeha [19] in a review of in vitro investigations on MITSOs concluded that effective factors on retention must be investigated separately under well-controlled conditions to limit the influence of confounding variables on the outcome. The current study accessed the effect of inter-implant distance on retention and resistance for a MITSO when subjected to dislodging forces. The MITSOs under function resist to dislodgement in different directions in the mouth. The outcome is a complex three-dimensional movement of the overdenture.

Therefore, to analyze this behavior in in vitro conditions, tensile dislodging forces were divided into simpler elements [5,9,10].

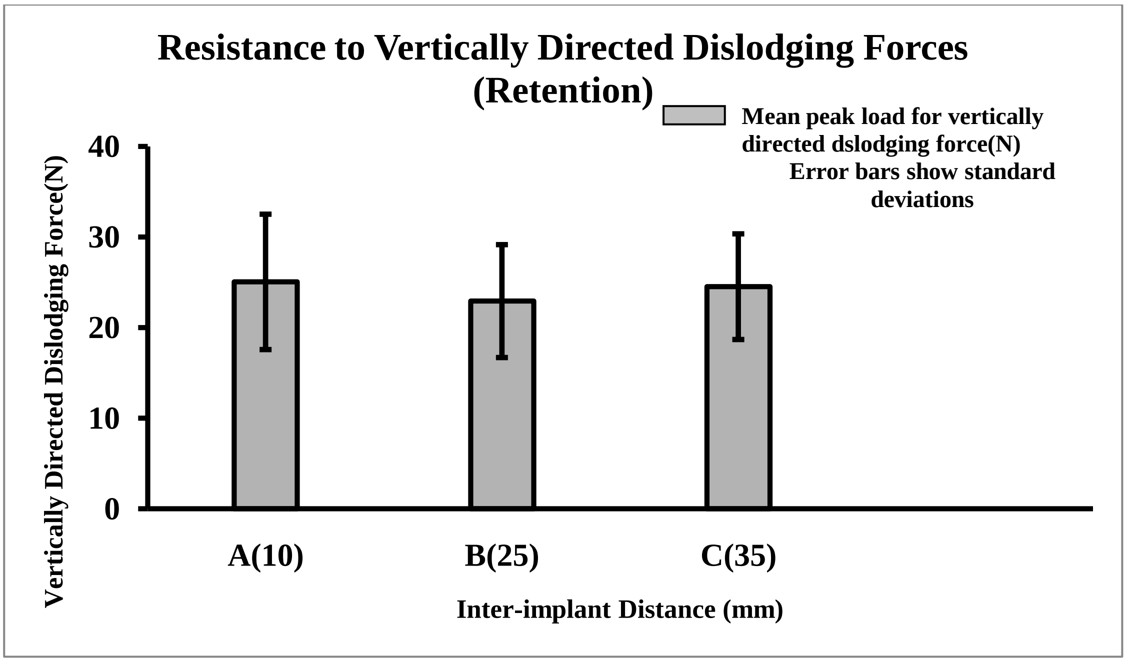

Fig 6. Mean values and standard deviations of the peak loads (N) for vertically directed dislodging forces for three inter-implant distances: A (10mm), B (25mm), and C (35mm)

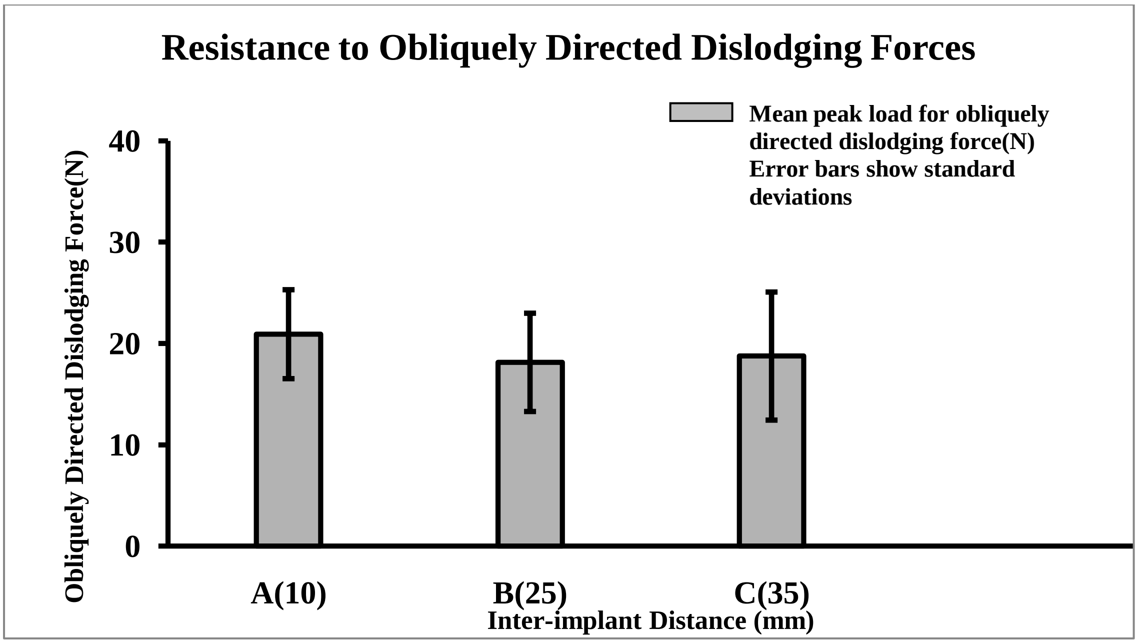

Fig 7. Mean values and standard deviations of the peak loads (N) for obliquely directed dislodging forces for three inter-implant distances: A (10mm), B (25mm), and C (35mm)

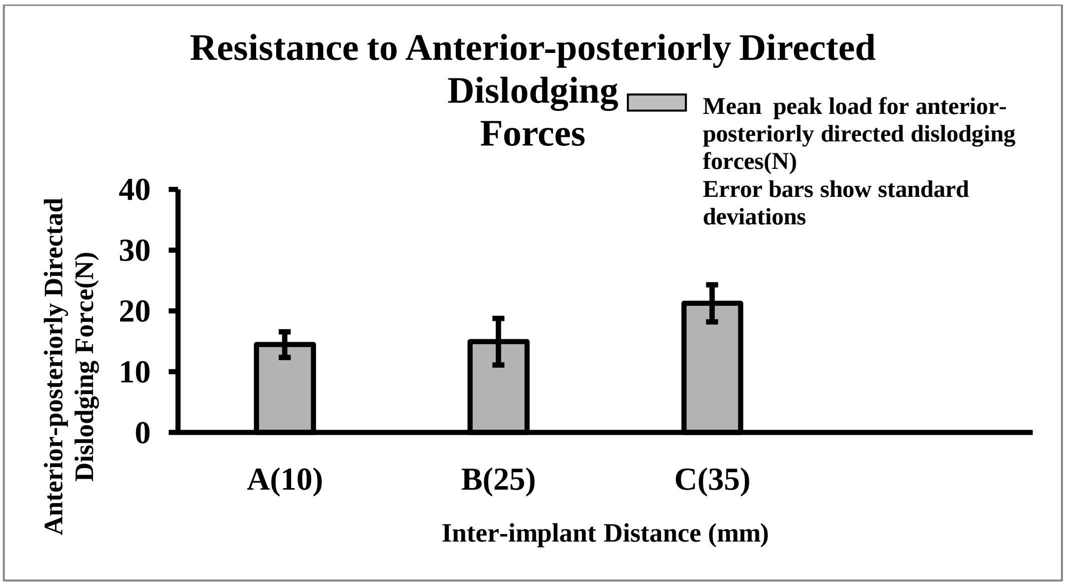

Fig 8. Mean values and standard deviations of the peak loads (N) for anterior-posteriorly directed dislodging forces for three inter-implant distances: A (10mm), B (25mm), and C (35mm)

In this study, the overdenture was examined in three principal directions: vertical, oblique and anterior-posterior.

The results of this investigation revealed that there were no significant differences in the peak loads among the three A, B, and C groups (the inter-implant distances of 10, 25, and 35 mm, respectively) with vertically and obliquely directed dislodging forces, while the peak loads with the anterior-posteriorly directed dislodging forces for group C were significantly the highest. Hence, the null hypothesis of the study was partly rejected.

Michelinakis [17] and Doukas [18] performed two in vitro studies in which they used the inter-implant distance of 19, 23 and 29 mm, and measured the peak loads in vertical direction. They found that the inter-implant distance played a significant role only in the retention produced by the Hader bar/red [17,18] and yellow [18] clips configuration and not by the other attachments including the ball/socket and magnet.

Although the exact same ball attachments were not used in the current investigation compared to the mentioned studies, the results of the current study regarding load measurements with vertically directed dislodging forces were similar to that of Michelinakis [17] and Doukas [18]. The retention was not affected by the inter-implant distance for MITSOs retained by two ball attachments. However, Michelinakis [17] and Doukas [18] had not measured the peak loads for obliquely and anterior-posteriorly directed dislodging forces. In order to better simulate the overdenture multidirectional movement, the peak loads should be measured with vertically, obliquely, and anterior-posteriorly directed dislodging forces.

The advantage of placing the implants in position C, which showed the highest resistance of overdenture to anterior-posteriorly directed dislodging forces, can be explained in physics and mechanics by the torque formula [23]:

$$\tau = rF \sin \phi$$

τ : Torque force
r : Distance from force to axis of rotation
F : Force
ϕ : Angle between F and r vectors
In different implant positions (A, B, and C), the amounts of $'F'$ and $'\phi'$ are constant while the amount of $'r'$ is variable depending on implant positions. In position C, the axis of rotation, a virtual line that passes through the centers of the implants, moves backward and the amount of $'r'$ for posterior forces is minimal. According to the above-mentioned formula, $'\tau'$ is minimal, thus the resistance against posterior forces is at its highest level as the results of the current investigation revealed. The significant difference between position C compared to A and B may be due to the arch curvature that causes greater anterior-posterior distance between B and C compared to A and B.
Based on the results of this study, placing implants with more inter-implant distance could be advantageous in increasing the resistance against anterior-posterior functional forces; however, it is unknown what effect this has on load distribution to the implants and mucosa. For MITSOs, the implants are proposed to be placed between the mental foramina. The mental foramen is usually located apical to the mandibular second premolar or between the apices of the premolars [16]. Although Tokuhisa [20] found that ball attachment could be advantageous in optimizing load transmission and minimizing overdenture movement compared to bar and magnet attachments, further studies are suggested considering both factors: inter-implant distance and load distribution to implants.
Van Kampen [14], Petropoulos [5,10,15], Tabatabaian [9], Setz [24], and Botega [25] evaluated the retention and resistance of MITSOs using two implants. However, the exact distance between the implants was not revealed. In the majority of the aforementioned studies, several attachment types were subjected to testing in order to measure the retention without concerning the inter-implant distance.
This investigation was performed on a test cast with a medium-sized, ovoid arch form using pink nylon inserts (soft retention of 800-950 g listed by manufacturer) and ball abutments with a specific size. These factors may have affected the results. Therefore, evaluation of their potential impact can be the subject of future studies.

CONCLUSION
Within the limitations of this study, it was concluded that the inter-implant distance did not affect vertical retention and oblique resistance of MITSOs; however, it affected anterior-posterior resistance to dislodgement. Therefore, regarding functional dislodging forces, the most possible inter-implant distance provides the best level of resistance. Based on the present study, to achieve the optimal outcome for MITSOs with regard to retention and resistance, clinicians should consider the inter-implant distance in placing implants.

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