Effect of Labial Implant Inclination on the Retention and Stability of Different Resilient Stud Attachments for Mandibular Implant Overdentures: An In Vitro Study

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Purpose: This study evaluated the influence of labial implant inclination on the retention and stability of different resilient stud attachments for mandibular implant overdentures. Materials and Methods: Four identical mandibular edentulous acrylic resin models were fabricated. For each model, two implants were inserted at the canine areas with different degrees of labial inclination: 0, 10, 20, and 30 degrees. Four experimental overdentures were fabricated over the models and fitted to the implants using resilient stud attachments. Regular retentive inserts (extra-light, light, and medium retention) were used for all implant inclinations, and extended-range inserts (extra-light and medium retention) were used for 30-degree inclination only. Vertical (retention) and oblique (stability) dislodging forces (lateral, anterior, and posterior) were evaluated initially (initial retention) and after overdenture insertion and removal (final retention). Results: After repeated insertions and removals, 30-degree inclination recorded the highest retention and lateral stability, and 0 degrees recorded the highest posterior stability; 20 degrees showed the lowest retention, and 30 degrees recorded the lowest posterior stability. The highest stability and retention values were recorded with light and medium regular regular inserts, and the lowest values were noted with extra-light regular inserts. Conclusion: Within the limits of this study, moderate labial implant inclination (10 degrees and 20 degrees) was shown to negatively affect retention and anterior/lateral stability, and excessive implant inclination (30 degrees) to negatively affect posterior stability. When implants are inclined labially, it is recommended to use light and medium regular stud attachments to obtain high levels of retention and stability for two-implant-retained overdentures. Int J Oral Maxillofac Implants 2019;34:381–389. doi: 10.11607/jomi.6789

Keywords: attachment, implant, inclination, Locator, overdenture, retention, stud

The use of two implants to retain mandibular overdentures is considered the minimum standard of care that should be given to the edentulous patient.¹ One of the most widely used attachments to retain these overdentures to the implants are resilient studs. Such attachments have dual retention, color-coded nylon inserts (according to retention degrees), and reduced height. The low profile of the attachment could be helpful in patients with reduced restorative space to avoid denture fracture.² Moreover, resilient studs have conventional inserts, which can be used up to 10-degree individual implant inclination. In addition, extended range inserts are indicated up to 20-degree inclination.³⁴

Buccolingual implant position depends mainly on the shape of mandibular anatomy and presence of concavities in the lingual surface of the mandible. It should be noted that orientation of implants at a right angle to the occlusal plane is sometimes impossible due to angulation of the alveolar bone labially or lingually. In such cases, insertion of an inclined implant is inevitable.⁵⁶ In agreement with this fact, Mericske-Stern⁵ reported that 70% of investigated patients showed a buccally deviated axis of the mandibular interforaminal implants. Clinically, Krennmair et al⁷...
concluded that facial inclination more than 6 degrees provides easier placement and removal of the implant overdentures, reduces attachment complications, and produces less stress on the attachment mechanism.8

Retention of dentures is defined as the resistance to vertical withdrawal forces, or denture resistance to removal in an opposite direction to that of its insertion.9 Stability is defined as the ability to resist rotational and horizontal forces that cause anteroposterior and lateral rocking of the prosthesis.10

The degree of implant inclination greatly affects peri-implant strains,11–13 retention,14–16 and prosthodontic maintenance3,8,14,17 of resilient stud attachments. In terms of prosthetic complications, wear, fracture, and replacement of retentive inserts may decrease prosthesis retention and consequently affect patient dissatisfaction.8

The impact of distal3,16,18 and mesial14,15,19 inclinations of implants on the retention of resilient stud attachments was evaluated. However, the evaluation of denture stability (resistance to nonaxial dislodging) was not evaluated, as previous studies were performed using acrylic blocks that did not simulate the actual mandibular anatomy. During mastication, overdentures are exposed to different dislodging forces at different speeds20,21 and the resultant force direction is a combination of vertical, horizontal, oblique, and rotational forces.19 Moreover, the impact of increased implant angulations (> 10 degrees) on the retention of conventional or extended-range male inserts of these attachments was not investigated. Accordingly, this study aimed to evaluate the effect of labial implant angulation on the retention and stability of different resilient stud inserts used to retain mandibular implant overdentures. The tested hypotheses were: (1) does labial implant inclination significantly affect the retention and stability of resilient studs?; and (2) does the type of resilient stud nylon insert significantly affect the retention and stability of these attachments? The null hypothesis was that there will be no significant effect of implant inclination or type of nylon insert on retention and stability of overdentures retained to implants with resilient stud attachments.

MATERIALS AND METHODS

Test Models
The guidelines for reporting in vitro studies (CRIS) were followed. Four identical edentulous mandibular acrylic models (without undercuts) were constructed.11 The models were mounted to a parallometer device (Biaggini Medical Devices). The parallometer drills were held perpendicularly to the ridge of each model.11–13,15 For all models, a clear acrylic guide template was constructed and used to mark implant positions at canine regions (Fig 1). Two depressions were drilled using successive drills held at the following degrees of labial inclination: 0 (model 1), 10 (model 2), 20 (model 3), and 30 degrees (model 4). Using a modified semicircular plastic protractor (Fig 2), the different implant inclinations were obtained by tilting the table of the machine labio-lingually to make the axis of the drills correspond to the degrees of the planned implant inclination.11–13,15 Two implants (3.7 × 13 mm, TioLogic, Dentaurum) were placed in each model in the prepared recesses to achieve the following degrees of labial inclination (Fig 3): 0, 10, 20, and 30 degrees. These inclinations are estimates since the plastic protractor measured to ± 1 degree. The implants were parallel to each other in the frontal plane and inclined labially in the sagittal plane. Implants were fixed to the acrylic models using chemical-cure acrylic resin. An average 1.5-mm-thick layer of chemical-cure resilient silicone soft liner (Permafix Kohler, Medizintechnik, Bodensee-allee) was used to simulate ridge mucosa.22,23

Experimental Overdentures
Twenty duplicate overdentures (five overdentures for each model) were constructed. This sample size was selected to provide a power of 99% (effect size = 1.4, and two-tailed α = .05) based on the results of a previous study15 in which the authors found a significant difference in retention values between different degrees of mesial implant inclinations. Each overdenture was composed of a heat-cure acrylic denture base and occlusion rim. A cobalt-chromium reinforcing framework was constructed over each model.
to enhance the strength of each overdenture. Four metal hooks (loops) were extended from the framework at the canine and second molar regions bilaterally. The occlusal plane was adjusted parallel to the horizontal plane. Resilient stud abutments (medium, 3 mm gingival height, TioLogic, Dentaurum) were threaded to the implants at 35-Ncm torque. Resilient stud matrices were snapped on the abutments and picked up to the experimental overdentures using self-cure acrylic resin. The following retentive inserts (Fig 4) were used:

- **Conventional inserts**: extra-light retention (blue, 680 g), light retention (pink, 1.365 g), and medium retention (transparent, 2.270 g). Conventional inserts were used for all implant inclinations.
- **Extended-range inserts**: extra-light retention (red, 680 g) and medium retention (green, 1.815 g). Extended-range inserts were used for 30-degree inclination only.

**Evaluation of Dislodging Forces**

For each model, axial, anterior, posterior, and lateral dislodgment were performed in a quasi-random manner to eliminate the effect of order of dislodgment direction on retention and stability measurements.

**Axial Dislodgment (Retention)**

A 15-cm-long custom-made iron chain (diameter of the rings = 6 mm) was connected to each hook of the overdenture. A metal plate of 5 × 5-cm dimensions with four perforations was joined to the chain end by adjustable screws (Fig 5). The metal plate was connected to the head of a universal testing machine (LLOYD LRX, LLOYD instruments) by an additional (main) chain screwed to the center of the plate. Before each measurement, adjustment of the four chains was done by tightening the screws to minimize slack of the chains. Each model was fixed to the base of the universal testing machine. To compensate for the weight of the overdenture and chains, the testing machine was balanced and calibrated using a computer algorithm. An axially directed four-point tensile load was applied on the metal plate until separation of the attachments occurred. A crosshead speed of 50 mm/min was used to approximate the denture dislodgment speed during mastication. The maximum load needed to separate the experimental overdenture was recorded in Newtons (N) to represent the retention force.

**Oblique (Nonaxial) Dislodging (Stability)**

The following nonaxial dislodgments were applied to simulate denture stability (Fig 6):

1. **Anterior dislodgment**: The load was applied in a posterior direction when the posterior two chains were disconnected and anterior chains were attached to the canine hooks (Fig 6a).
2. **Posterior dislodgment**: The load was applied in an anterior direction when the anterior two chains were disconnected and the posterior chains were attached to the molar hooks (Fig 6b).
3. **Lateral dislodgment**: The load was applied in the left direction when the chains were connected to the canine and molar hooks of the right side and the left two chains were disconnected (Fig 6c).

The two-pointed axial force (obliquely directed force) that needed to separate the attachments was calculated (in Newtons). Five measurements were recorded for all directions of dislodging forces with each type of retentive insert (one for each experimental denture), and the mean was calculated as initial retention values.

Each experimental overdenture was pulled out and reinserted 540 times to simulate denture use over a period of 6 months (assuming three insertions and removals of the prosthesis per day for hygiene purposes). Again, five measurements (one for each
experimental denture) were recorded, and the mean was calculated to represent the final retention. All measurements were made by one blinded calibrated examiner with sufficient experience in retention measurement (I.A.M.). Outlier retention forces were excluded from data analysis. A workflow diagram of all measurements is presented in Fig 7.

**Statistical Analysis**
Mixed analysis of variance (ANOVA) was used to test the difference in retention and stability forces (dependent variable). The independent variables were groups (0, 10, 20, and 30 degrees) and nylon inserts (extra-light, light, and medium conventional, and extra-light and medium extended range). The repeated measures independent
variable was time of measurements (initial and final). Multiple comparisons were made using the Bonferroni test. The $P$ value was significant if it was ≤ .05.

**RESULTS**

**Retention (Vertical Dislodging)**
Retention (N) of different inclinations and different types of resilient studs during vertical dislodging is shown in Table 1. The highest retention (initial/final) was noted with 30 degrees, and the lowest retention was observed with 20 degrees for all inserts ($P < .001$). For 0, 10, and 20 degrees, the highest initial and final retention was observed with conventional medium inserts, and the lowest retention was noted with conventional extra-light inserts. For 30 degrees, the highest initial and final retention was noted with conventional medium inserts ($P < .001$). The lowest initial retention was observed with conventional extra-light inserts, and the lowest final retention was observed with conventional light inserts ($P < .001$). With the exception of 20 and 30 degrees of conventional extra-light inserts, initial retention was significantly higher than final retention ($P < .001$).

**Stability (Oblique Dislodging)**
Stability values (N) of different angulations and types of resilient studs during anterior, posterior, and lateral dislodging are shown in Tables 2, 3, and 4, respectively. For all inserts, the highest initial stability during anterior dislodging was observed with 30 degrees, and the lowest stability was observed with 10 degrees ($P < .001$). The highest initial stability during posterior dislodging was recorded with 0 degrees, and the lowest stability was recorded with 30 degrees ($P < .001$). The highest initial stability during lateral dislodging was recorded with 0 degrees, and the lowest stability was observed with 30 degrees ($P < .001$). The highest final stability during posterior dislodging was recorded with 0 degrees, and the lowest stability was observed with 30 degrees, and the lowest stability was observed with 10 degrees ($P < .001$).

For anterior, posterior, and lateral dislodging forces, conventional medium inserts were associated with the highest stability, and conventional extra-light inserts recorded the lowest stability. With the exception of 10 degrees (anterior dislodging), 20 degrees (posterior dislodging), and 30 degrees (lateral dislodging), initial retention was significantly higher than final retention ($P < .002$).

**DISCUSSION**

The mucosa was simulated, as it may affect the behavior of attachment separation especially during nonaxial dislodging.$^{15}$ In the present study, the initial retention of different types of resilient stud attachments ranged from 7.7 to 51.7 N. These values are within the limits of minimal accepted retention for mandibular overdentures (8 N).$^{30,32}$

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<table>
<thead>
<tr>
<th>Table 1</th>
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### Table 2  Stability Forces During Anterior Dislodging (N) of Different Implant Angulations and Resilient Stud Inserts

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### Table 3  Stability Forces During Posterior Dislodging (N) of Different Implant Angulations and Resilient Stud Inserts

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### Table 4  Stability Forces During Lateral Dislodging (N) of Different Implant Angulations and Resilient Stud Inserts

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</table>
The highest initial retention and anterior stability was recorded with 30 degrees. Also, the highest final retention and lateral stability was noted with 30 degrees. Similarly, Rabbani et al.\textsuperscript{19} noted an increase in the retention of resilient stud inserts by the increase in the degree of mesial implant inclination of two implants retaining overdentures. In this study, the increased retention with excessive implant inclination may be attributed to the excessive labial undercuts created by labial inclination of resilient stud abutments, which increase the resistance to vertical and anterior dislodgment as these forces are applied perpendicular to the resilient stud abutments. These undercuts may interlock the nylon inserts with labial surfaces of the resilient stud abutments and prevent escapement of the inserts during vertical dislodging. However, in clinical situations, the use of regular nylon inserts with higher implant angulation, although not affecting the retention, may be associated with higher peri-implant strains, which may cause bone microdamage and resorption.\textsuperscript{19} The increased lateral stability with 30 degrees may be attributed to the path of rotation during lateral dislodging, which is in a direction opposite to the direction of implant inclination.

The lowest initial and final retention was observed with 20 degrees, and the lowest anterior and lateral stability was observed with 10 degrees for all inserts. The decreased retention with 20-degree labially inclined implants is in line with the findings of Evtimovska et al.,\textsuperscript{16} who concluded that the greatest loss of overdenture retentive force occurred with a pair of resilient stud attachments when implants are inserted with 20-degree distal inclination. The decreased final retention with increased angulation up to 20-degree inclination concurred with the results of previous studies.\textsuperscript{14,33} Ortegón et al.\textsuperscript{33} found significant reduction in retention at 20-degree implant angulation. The decreased retention may be due to the wear of the resilient stud inserts, which occurs more quickly at 20 degrees.\textsuperscript{14} However, at 30 degrees, the excessive implant inclination may eliminate the effect of attachment wear and cause an increase in retention forces. The decreased anterior and lateral stability with 10 degrees may be due to undercuts created by 10-degree labial inclination being moderate. Such undercuts allow nylon inserts to escape more easily with 10-degree inclination than 30-degree inclination and enhance the wear of the nylon inserts.\textsuperscript{15} Even if wear/damage of the nylon inserts occurred with large implant angulation (30 degrees), excessive undercuts still provide increased retention.\textsuperscript{15}

The highest initial posterior and lateral stability and the highest final anterior and posterior stability was observed with 0 degrees, and the lowest stability was observed with 20 degrees. The lowest posterior stability was recorded with 30 degrees. Since no previous published studies were concerned with evaluation of the effect of implant angulation on stability of implant overdenture attachments, direct comparison of the study findings to the results of other studies was not possible. However, it could be concluded that initial stability of the inserts increased with parallel implants. The decreased stability with 30 degrees during posterior dislodging may be attributed to the posteroanterior overdenture rotation, which occurs in the same direction of implant inclination causing minimal friction with resilient stud matrices and rapid disengagement of nylon inserts. The reduction of the undercut in the lingual side of the abutments facilitates nylon insert disengagement during posterior dislodging.\textsuperscript{3} Clinically, it may be recommended for patients who had labially inclined implants to remove the resilient stud-retained overdentures by applying tissue-away forces to the posterior denture saddles, as posterior dislodging forces were associated with minimal resistance to removal. Moreover, these patients should avoid removal of the denture by application of anterior dislodging forces over the attachments, as excessive retention may transmit moment loads on the implant during denture removal.

For the majority of implant inclinations, conventional medium inserts showed the highest initial and final retention and stability, followed by conventional light and extended-range medium inserts. Extended-range extra-light and conventional extra-light inserts recorded the lowest retention and stability. In agreement with this finding, Rabbani et al,\textsuperscript{19} in a recent study, found a great reduction in retention with conventional extra-light inserts after 720 cycles for mesially angled implants up to 10 degrees. They also noted that conventional medium inserts were associated with the highest retentive values. It could be concluded that, clinically, in terms of cost effectiveness, the best option may be the conventional medium inserts with all degrees of implant inclination.\textsuperscript{34} Conversely, Evtimovska et al\textsuperscript{16} concluded that retentive values of the conventional and extended-range medium inserts are reduced significantly after repeated insertions and removals when these inserts are used for nonparallel (20 degrees divergent) implants. They attributed the decreased retention to the wear of nylon inserts upon removal from the abutments. The decreased retention and stability of red inserts after wear simulation may be due to these inserts being designed by the manufacturer for excessive implant angulation without internal frictional flange.\textsuperscript{3,30}

With the exception of 20 and 30 degrees of conventional extra-light inserts, the initial retention was significantly higher than the final retention. This finding was expected and is in agreement with several in
This retention loss can be described by surface changes in the nylon components during loading.\textsuperscript{3,5,6} The retention loss may be due to frictional contact, which arises from dimensional misfit between the slightly oversized male nylon insert and the inner ring of the female abutment.\textsuperscript{37}

For 20- and 30-degree inclination, the retention of conventional extra-light inserts increased after insertions and removals compared with initial retention. Also, the stability against posterior and lateral dislodging increased following 540 pulls compared with initial stability. It seems that surface degradation of the nylon insert does not produce a proportional deterioration in retention and stability with increased implant angulation. A similar finding was also reported in other studies.\textsuperscript{38,39} The surface deterioration may induce roughness and creep and produce a corresponding increase in retention by micromechanical friction.\textsuperscript{38} The large undercuts produced by increased implant angulation may increase friction forces with deteriorated inserts and could be responsible for increased retention.

Although in vitro studies allow standardization of the tests by excluding oral conditions, the present study has several limitations. The absence of saliva increases the friction between the patrices and matrices of the attachments, which could minimize wear and increase the retentive force.\textsuperscript{40,41} Furthermore, using nonaxial dislodging to simulate denture stability is relatively simplistic and does not present the true in vivo nonaxial dislodging forces to which the denture base can be subjected. Moreover, the several confounding variables included in this study may mask or falsely demonstrate an actual association between the procedure and outcome when no real association between them exists. However, randomization of order of dislodgment direction reduced this effect. Another limitation in this study is the potential bias. The methodology of measuring retention and stability was previously developed by the first author and used in several previous studies.\textsuperscript{3,15,24,26,27,35} This study was a part of a research project that evaluated the effect of degree and direction of implant inclination on retention and stability of different resilient stud inserts used to stabilize implant overdentures. Therefore, publication bias, information bias, confirmation bias, and measurement bias should be taken into account. These sources of bias by the participants make it difficult to conduct the study in a totally objective manner, as the “principle of suspicion” requires sensitivity to possible “biases” and “systematic distortions.” However, blinding of the person who collected the data may reduce the risk of bias. Therefore, overinterpretation of the results of this study should be avoided.

Suggestions for improvement in future studies include the use of artificial saliva, cyclic dislodging to test the retention values over an extended period of time, and calculation of the angle of paraxial dislodgment. Future clinical trials are needed to evaluate the clinical retentive values, prosthetic complications, and maintenance of different resilient stud inserts used to stabilize overdentures to inclined implants.

**CONCLUSIONS**

Within the limits of this study, only moderate labial implant inclination (10 and 20 degrees) negatively affects retention, anterior, and lateral stability, and excessive implant inclination (30 degrees) negatively affects posterior stability. When implants are inclined labially, it is recommended to use conventional light and medium inserts of resilient stud attachments to obtain high levels of retention and stability of two-implant–retained overdentures.

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