Resilient Stud Versus Bar Attachments for Inclined Implants Supporting Mandibular Overdentures. An In Vitro Study of Loading and Dislodging Strains

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Purpose: To evaluate strain around resilient stud and bar attachments for inclined implants supporting mandibular overdentures during loading and dislodging. Materials and Methods: A mandibular edentulous model was printed using the laser sintering technique. Two vertical implants and two 30-degree distally inclined implants were placed in canine and premolar areas, respectively. Overdentures were attached to the implants with either a resilient stud (Locator, group 1) or a bar/clip (group 2) attachment. Three strain gauges were mounted at the buccal, lingual, and proximal surfaces of each implant. Microstrains were registered during vertical loading and dislodging force applications and compared between attachments (resilient stud and bar) and implant positions (vertical and inclined). Results: For canine implants, bar overdentures recorded significantly higher microstrains than Locator overdentures during vertical loading. For premolar (inclined) implants, Locator overdentures recorded significantly higher microstrains than bar overdentures during vertical dislodging. For both groups (during loading) and the bar overdenture group (during dislodging), canine (vertical) implants showed significantly higher microstrains than premolar (inclined) implants. Conclusion: Within the limitations of this in vitro study, canine (vertical) implants may be at risk of increased stresses during loading if bar attachments are used for vertical and inclined implants supporting mandibular overdentures, and premolar (inclined) implants may be at risk of increased stresses during dislodging if Locator attachments are used. For both attachments, canine implants showed significantly higher microstrains than premolar implants during loading and dislodging. Int J Oral Maxillofac Implants 2022;37:982–988. doi: 10.11607/jomi.9560

Keywords: attachment, bar, implants, inclined, overdenture, resilient stud, strain

Edentulous patients with resorbed mandibles may experience problems with conventional dentures because of impaired load-bearing capacity and loss of stability and retention.1 For those patients, four-implant–supported overdentures are indicated to minimize soft tissue support and avoid high muscle attachment–sensitive mucosa and superficial mental nerve.2 When these implants are inserted parallel to each other in the interforaminal region, the fixed prosthesis requires cantilevers to obtain the necessary occlusal contact.3 The adoption of tilted implants for the rehabilitation of edentulous mandibles with fixed prostheses has been proposed in the last two decades to avoid damage to the mandibular nerve and the morbidity of bone-grafting procedures. The tilted implants increase the anteroposterior spread and the interimplant distance while reducing cantilever length of the prosthesis, allowing for the use of longer implants and providing wide prosthetic support and better load distribution.4,5 Maló et al6 described the use of four implants (two vertical implants in the anterior region and two premolar implants placed with 30-degree distal inclination) to support immediately loaded full-arch fixed prostheses and named the approach the All-on-4 treatment concept (Nobel Biocare). However, in patients with moderate to severe bone resorption, the fixed prosthesis may be compromised with excessive overlap of the prosthesis flange onto the residual ridge, which may compromise hygienic maintenance.7 Moreover, the location of the mental foramen may preclude sufficient tilting of the premolar implants needed to eliminate the cantilevers when the fixed restoration is used. In these patients, an overdenture can be a reliable alternative to a...
fixed prosthesis, especially for patients with advanced bone atrophy, lost lip support, long clinical crowns, or increased interarch space. Furthermore, overdentures are indicated with an unfavorable jaw relationship and can be removed at night to avoid implant overloading if bruxism exists. Recently, the present authors described the use of milled bar overdentures as a definitive prosthetic rehabilitation for patients restored with four implants according to the All-on-4 protocol and compared this prosthetic approach to the conventional full-arch fixed restoration. Other studies reported the use of bar-retained overdentures on inclined implants as an alternative to metal-acrylic implant-supported fixed prostheses.

Attachments can be used to retain overdentures to implants, such as splinted (bar/clip) or nonsplinted (stud) attachments. Resilient studs (Locator attachments) have reduced vertical height, can be replaced easily, provide different degrees of retention, and can compensate for implant disparallelism. Moreover, Locators occupy less space within the denture base, are easier to clean, and are less technique-sensitive than splinted designs. The manufacturers recommend regular plastic inserts (with internal and external friction) where interimplant angulation ranges from 0 to 20 degrees. Extended-range inserts (external friction only) are indicated if interimplant angles exceed 20 degrees. Bar attachments distribute the load between the implants, can be used with divergent implants, have a reduced rate of prosthetic complications, and provide horizontal stability when the ridge is resorbed. When selecting the attachment type, several factors should be considered, such as cost, patient preferences, denture hygiene, maintenance, and stress/strain magnitude transmitted to the implants.

The International Journal of Oral & Maxillofacial Implants

MATERIALS AND METHODS

Experimental Setup

The testing model used in this study represents a real-life experiment for a completely edentulous patient with a moderately atrophied mandibular ridge who received inclined implants and an All-on-4 fixed restoration in a previous study. The implants were placed using a stereolithographic surgical guide and computer-guided surgery. CBCT (Vatech) was performed, and a 3D mandibular edentulous model was printed using the laser sintering technique (FLDGOR01, Formlabs). An acrylic resin base was added to each model to facilitate the fixation of the model to the testing device. Using the CBCT software (OnDemand 3D, CyberMed), four implants were planned in the interforaminal area of the mandible. Two implants were planned vertically in canine areas, and two premolar implants were planned with 30-degree distal implant inclination. The plan was used to print a bone-supported stereolithographic guide for implant placement. The guide was fixed on the model using fixation pins, and osteotomy preparation was done using the universal surgical kit (In2Guide, CyberMed; Fig 1). Four implants (3.7 × 13 mm, Dentaurum) were cemented in the prepared sites using resin cement to simulate osseointegration. Cover screws were threaded to the implant platforms to close implant orifices. The models were covered by autopolymerized silicone resilient denture liner (Permaflex, Kohler) to simulate patient mucosa (average thickness of the mucosa of the patient [1.5 mm] was calculated using CBCT software).

For standardization of strain gauge positions, the same model was used for both groups. Locator (group 1) and bar (group 2) abutments (mucosal height: 3 mm) were threaded to the implants at 30-Ncm torque. A total of 40 duplicate mandibular overdentures (20 overdentures/group) were made based on the results of previous studies in which the authors found a significant difference in microstrains between two groups of implant overdentures. The sample size was calculated to give 80% power in the results of this study (independent t test, type I error = 0.05, effect size = 0.86) using a computer program (G*Power, version 3.1.5). The overdentures were composed of acrylic resin bases and occlusion rims. For Locator overdentures (group 1), metal housings with black inserts were placed on the abutments. The dentures were attached to the Locator housings using autopolymerized acrylic resin. The black inserts were replaced with blue inserts (extra-light retention: 680 g) for vertical implants and red extended-range inserts (extra-light retention: 680 g) for inclined implants (Fig 2). The blue inserts were designed by the manufacturer for vertical implants and had internal and external frictional flanges. The red extended-range inserts were
designed for angled implants and had an external frictional flange only, without an internal flange. For bar overdentures, straight multiunit abutments (Dentaurum) were connected to canine implants and angled multiunit abutments were connected to premolar implants. The plastic caps of multiunit abutments were waxed to a resin pattern of a Hader bar (RHEIN 83). The resin bar was cast in cobalt-chromium. Four plastic clips (yellow, light retention, RHEIN 83) were attached to the top of the bar (two clips between canine implants and one clip between the canine and premolar implants on each side). The dentures were attached to the clips using autopolymerized acrylic resin (Fig 3).

**Strain Measurements**
The lining material was excised from buccal, lingual, and proximal surfaces of the implants, and three linear strain gauges (resistance: 119.6% ± 0.4% Ω; gauge length: 1 mm; gauge factor: 2.08% ± 1.0%, Kyowa Electronic Instruments) were bonded to the surface of the model around each implant after flattening the model surface under the gauges. The long axes of the gauges were oriented parallel to the long axes of the implants buccally and lingually and perpendicular to the axes of the implants interproximally, and the gauges were bonded to the model using a special bonding agent (CC-33A, EP-34B, Kyowa; Fig 2a). To control thermal changes during load application, an acrylic dummy gauge was connected to each active gauge in a half-circuit Wheatstone bridge (Tokyo Sokki Kenkyujo). The rest of the bridge was connected to a digital device (Tinsley). The changes in the resistance of the gauges were amplified and outputted in volts (microstrains, µs). Calibration of the gauges was made before load application to ensure the linear...
relation between applied force and produced microstrain. Microstrains were registered during vertical loading and dislodging force applications, then compared between groups (resilient stud and bars) and implant positions (vertical and inclined). A fully digital testing device (LLOYD) was utilized to deliver a vertical static force of 60 N (an amount that is similar to maximum occlusal force for individuals wearing implant overdentures)\(^\text{35}\) in a compressive mode controlled by software (cross-head speed = 0.5 mm/second). The load was applied bilaterally over a metal bar placed on the occlusion rim at the areas of the first molar teeth to mimic biting in centric occlusion\(^\text{32–34,36}\) (Fig 4a). Four metal hooks were embedded in the occlusal surface of each denture at the canine and first molar areas. A metal plate with four metal chains attached to the hooks was used to apply vertical dislodging forces in a tensile mode at 50 mm/minute crosshead speed to simulate the velocity of overdenture removal during chewing\(^\text{36–38}\) (Fig 4b). All measurements were made five times for loading and dislodging conditions in each group, allowing 5 minutes for heat dissipation/recovery, and the mean microstrains were used.

**Statistical Analysis**

The absolute values of the mean microstrain of the three gauges around each implant were subjected to statistical analysis. Data were analyzed with the SPSS program (version 25, SPSS). The data were nonparametric as verified by Shapiro-Wilk test. Mann-Whitney test was applied to test significant differences in microstrain values between groups (Locator or bar overdentures) and implant positions (vertical and inclined). \(P < .05\) was considered significant.

**RESULTS**

During vertical loading and dislodging, no significant difference in microstrains was detected between right and left implants. Therefore, microstrains were averaged and the mean was used. A comparison of microstrains between groups and implant positions during vertical loading toward the tissue is presented in Table 1. There was a significant difference in the median microstrains between groups for canine (vertical) implants only \((P = .009)\). However, from premolar (inclined) implants, there was no significant difference in microstrains between groups. For canine implants, bar overdentures recorded significantly higher microstrains than Locator overdentures. For both groups, canine implants showed significantly higher microstrains than premolar implants during vertical loading \((P = .048\) and \(.004\) for Locators on the bar overdentures, respectively).

A comparison of microstrains between groups and implant positions during vertical dislodging is presented in Table 2. A significant difference in median microstrain values between groups was observed for premolar (inclined) implants only \((P = .049)\). However, for canine (vertical) implants, there was no difference in microstrains between groups. For premolar implants, Locator overdentures recorded significantly higher microstrains than bar overdentures \((P = .049)\). For the Locator overdenture group, there was no difference in microstrains between the canine and premolar implants. For the bar overdenture group, canine implants showed significantly higher microstrains than premolar implants \((P = .045)\).

**DISCUSSION**

One of the major problems/limitations of in vitro studies is the fact that these studies are usually conducted in standardized conditions that do not represent the clinical situation or reality. For example, the direction of implant inclination is dependent on the ridge anatomy and undercuts. Moreover, the degree of ridge atrophy and location of mental foramina may also affect the interimplant distance. In addition, the thickness of oral mucosa may vary from patient to patient. All these factors may affect stress transmission to the implants. Since the anatomical state of the mandible may be responsible for the amount of load that can be transferred to the peri-implant region,\(^\text{28}\) a positive replica of a natural mandible of
an edentulous patient was used as an experimental edentulous model.

Extended-range inserts (with external friction only) are advocated by the manufacturer if interimplant angles exceed 20 degrees. The manufacturer recommends a 40-degree angle as a maximum limit of angulation between two implants. The canine implant was inserted vertically (in line with the path of denture insertion), and the premolar implant was inclined 30 degrees from the vertical plane; consequently, the interimplant angle was 30 degrees and did not exceed the 40-degree limit. Therefore, extended-range inserts were used for inclined implants. To standardize the retentive caps in both groups, four plastic clips were used in the bar group. Locator extra-light retention inserts were used to avoid increasing peri-implant strains, as it has been demonstrated that stresses around angled implants increased when the retention forces of Locator inserts increased, and extra-light retention extended-range inserts (red inserts) were found to reduce peri-implant stresses when used over excessively inclined implants. Three gauges only were mounted around each implant, as there was not enough space to place strain gauges at the distal aspects of canine implants and mesial aspects of premolar implants due to the proximity of the canine and premolar implants to each other. In this study, the recorded microstrains at buccal, lingual, and proximal surfaces of each implant were averaged and the mean was used. This was done to avoid creation of another variable (implant surface), which would complicate statistical comparisons with three-way statistics (group, implant positions, and implant surface). Consequently, interpretation of the results would be difficult.

Overall, the null hypothesis was rejected since a significant difference in microstrains around implants was noted between the tested attachments. For vertical (canine implants), bar overdentures recorded significantly higher microstrains than Locator overdentures during vertical loading. The increased microstrains with bar overdentures at canine implants could be attributed to the position of the load application. When the load was applied to the first molar area, the forces were transmitted to the posterior portion of the bar and the cantilevers. The bar rigidly connects and splints the anterior and posterior implants together. Therefore, the load was transferred to canine implants, which could be responsible for the increased microstrains around the canine implants in the bar group. In contrast, the decreased microstrains with Locator overdentures may be attributed to the nonsplinting nature of Locator attachments. Therefore, the increased load on premolar implants (which is positioned nearly under the site of load application) did not transfer to canine implants. Moreover, the resiliency of Locator attachments was responsible for decreased load and peri-implant strains on canine implants. This resiliency resulted from the space created by the replacement of the black processing inserts with nylon inserts (approximately 0.2 mm).

For premolar implants, Locator overdentures recorded significantly higher microstrains than bar overdentures during vertical dislodging. This may be due to inclined premolar implants creating distal undercuts in the Locator abutments. These undercuts may be responsible for increased friction of red inserts with Locator abutments during dislodging and transferring more stresses to premolar implants. In the clinical setting, such undercuts create excessive retention forces during denture removal from angled implants. The increased retention forces may be responsible for increased stresses around implants, as peri-implant stresses were found to have a direct positive correlation with retention forces when Locator inserts were used for angled implants. Moreover, the increased retention forces of Locator inserts are

### Table 1: Microstrain (µs) of Groups and Implant Positions During Vertical Loading

<table>
<thead>
<tr>
<th></th>
<th>Canine (vertical) implants</th>
<th>Premolar (inclined) implants</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Locator overdentures</strong></td>
<td>Mean 168.00</td>
<td>106.00</td>
<td>.048*</td>
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<tr>
<td></td>
<td>SD 89.24</td>
<td>30.16</td>
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</tr>
<tr>
<td></td>
<td>Median 135.00</td>
<td>92.50</td>
<td></td>
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<tr>
<td></td>
<td>Minimum 90.00</td>
<td>80.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maximum 315.00</td>
<td>160.00</td>
<td></td>
</tr>
<tr>
<td><strong>Bar overdentures</strong></td>
<td>Mean 218.25</td>
<td>94.75</td>
<td>.004*</td>
</tr>
<tr>
<td></td>
<td>SD 195.89</td>
<td>10.32</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median 122.00</td>
<td>92.50</td>
<td></td>
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<tr>
<td></td>
<td>Minimum 80.00</td>
<td>85.00</td>
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<td></td>
<td>Maximum 675.00</td>
<td>110.00</td>
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</tbody>
</table>

*P is significant at .05.

### Table 2: Microstrain (µs) of Groups and Implant Positions During Vertical Dislodging

<table>
<thead>
<tr>
<th></th>
<th>Canine (vertical) implants</th>
<th>Premolar (inclined) implants</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Locator overdentures</strong></td>
<td>Mean 133.25</td>
<td>135.00</td>
<td>.69</td>
</tr>
<tr>
<td></td>
<td>SD 62.60</td>
<td>65.04</td>
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<td></td>
<td>Median 112.50</td>
<td>105.00</td>
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<td></td>
<td>Minimum 80.00</td>
<td>75.00</td>
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<tr>
<td></td>
<td>Maximum 290.00</td>
<td>285.00</td>
<td></td>
</tr>
<tr>
<td><strong>Bar overdentures</strong></td>
<td>Mean 104.00</td>
<td>98.50</td>
<td>.045*</td>
</tr>
<tr>
<td></td>
<td>SD 20.43</td>
<td>11.98</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median 100.00</td>
<td>77.50</td>
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<tr>
<td></td>
<td>Minimum 80.00</td>
<td>85.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maximum 140.00</td>
<td>125.00</td>
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</tr>
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*P is significant at .05.
associated with relevant signs of deterioration in clinical use, especially for tilted implants, which may necessitate frequent replacement of nylon inserts. The increased microstrains with Locator attachments concurred with the results of another study in which the authors reported increased peri-implant stresses with angulated Locator attachments used to retain mandibular overdentures during dislodging.

In contrast, in the bar group, the disengagement of the overdentures occurs on the level of the bar, as the plastic clip between canine and premolar implants on each side can disengage easily during dislodging. The splinting effect of the bar and the fact that stresses are transferred indirectly to premolar implants through the bar may be responsible for reduced strain around premolar implants in the bar group.

For both groups, canine implants showed significantly higher microstrains than premolar implants during loading. In the Locator group, the increased strain with the canine implant could be due to the increased vertical resiliency of red inserts, which have no internal frictional flange, thus enhancing overdenture rotation. Therefore, the cantilever action of the denture saddles creates a first class lever, and the fulcrum line is transferred to the canine implants anteriorly. The double frictional flange, together with the limited hinge movement of blue nylon inserts, counteracts canine implant rotation and could be responsible for the increased load on canine implants. The reduced load on inclined implants may be due to reduced friction of the red inserts with the abutments, as they had only an external flange. In line with this explanation, Elsyad et al found that the use of red inserts on two distally inclined implants for overdentures with Locator anchors results in a significant reduction of stresses transmitted to the implants. In the bar group, the decreased strain on premolar implants may be due to tilting of premolar implants allowing for a reduction in the cantilever length of denture saddles, increased anterior-posterior spread, and better and wide load distribution, resulting in decreased peri-implant bone stress. Similarly, other finite element analysis studies found that tilted distal implants, rigidly splinted with a fixed prosthesis, decreased peri-implant bone stresses compared to vertical implants. In line with this finding, Wismeijer et al noted that when four implants were connected to each other with rigid bar superstructures, there was significantly more bone loss and unfavorable strain around the central two implants in comparison with the posterior implants. Moreover, other clinical studies showed increased marginal bone loss around medially positioned vertical implants compared to distally tilted implants for fixed prostheses.

During dislodging in the bar overdenture group, canine implants showed significantly higher microstrains than premolar implants. This may be attributed to the positions of clips over the bar. The presence of two clips in the bar segment connecting the canine implants may increase retention forces and cause slow disengagement of the overdentures from the bar, which may transfer greater stresses onto the canine implants. In contrast, the presence of only one clip on the bar segments between the canine and premolar implants makes the posterior portion of the overdenture disengage easily, thus transferring reduced stresses to premolar implants during dislodging.

When evaluating stresses around the implants, in vitro studies are preferred over clinical trials, as in clinical settings, it is difficult to control factors such as bone density between implant sites, angulations of implants, direction and magnitude of forces, the fitness of the prosthesis, and resilience of ridge mucosa. However, in the present study, only the effect of axial loading was investigated. The absence of nonaxial loading is a limitation of this study because in the clinical setting, the prosthesis is subjected to complex forces of axial and nonaxial loads. Also, the absence of the fourth strain gauge around each implant and the lack of comparison between implant surfaces are considered other limitations. Future randomized clinical trials are needed to compare marginal bone levels around vertical and inclined implants supporting mandibular overdentures with bar and Locator attachments.

CONCLUSIONS

Within the limitations of this in vitro study, canine implants may be at risk of increased overload during loading if bar attachments are used for vertical and inclined implants supporting mandibular overdentures, and premolar implants may be at risk of increased overload during dislodging if Locator attachments are used. For both attachments, canine implants showed significantly higher microstrains than premolar implants during loading and dislodging.

ACKNOWLEDGMENTS

The authors reported no conflicts of interest related to this study. This study was self-funded by the authors.

REFERENCES


