# The Influence of Implant Inclination on Retention and Peri-implant Stresses of Stud-Retained Implant Overdentures During Axial and Nonaxial Dislodgments: An In Vitro Study

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Purpose: The purpose of this study was to evaluate the influence of implant inclination on retention and peri-implant stresses of stud-retained implant overdentures during axial and nonaxial dislodgments. Materials and Methods: Mandibular acrylic models (n = 4) received two implants in the canine areas with 0-, 5-, 10-, and 20-degree lingual inclinations. Dentures were attached to the implants with stud connectors. Four strain gauges were bonded at buccal, lingual, mesial, and distal surfaces **[AU: of a strain beta strain b** (microstrains, µs) were recorded during axial (vertical) and nonaxial (anterior, posterior, and lateral) dislodging. A general linear model was used to compare retention forces and implant stresses between implant inclinations and dislodging direction. In addition, a linear regression model was used to test correlation of implant stresses with confounding factors. Results: The highest retention and implant stresses were noted with 0 degrees, followed by 5 and 10 degrees (without difference), and the lowest values were noted with 20 degrees. Anterior dislodging was associated with the highest retention and implant stresses, followed by vertical dislodging, then lateral dislodging, and posterior dislodging. Periimplant stresses significantly correlated with dislodging direction and retention forces. Every 1 N of increase in retention forces causes 19.17 µs increase in implant stresses. Anterior dislodging was associated with the highest predicted stress values (846.0 µs), and the lowest stress values (143.41 µs) were associated with posterior dislodging. Conclusion: Retention forces and peri-implant stresses decreased as lingual implant inclination increased during axial and nonaxial dislodging of stud-retained implant overdentures. Peri-implant stresses were significantly correlated with dislodging direction and retentive forces. Int J Oral Maxillofac Implants 2020;35:XXX-XXX. doi: 10.11607/jomi.7954

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For the majority of patients, an overdenture on two implants is considered the minimum prosthetic care when complaining about the lack of retention and stability of mandibular dentures.<sup>1,2</sup> The overdenture retained by two implants is an effective approach, as it is simple, less traumatic, and cost effective.<sup>3</sup> Overdentures may be connected to the implants with splinted (bars) or unsplinted attachments.<sup>4</sup> The unsplinted attachments comprise balls, magnets, double crowns, or studs.<sup>5</sup> Locator attachments are a type of resilient stud and are one of the most popular attachment systems since their introduction in 2001.<sup>6</sup> Locators are resilient connectors that can be utilized in cases with inadequate interridge space to avoid denture base fracture.<sup>7</sup> The attachment provides sufficient retention by friction between the nylon inserts and the outer ring of the stud abutments.<sup>8</sup> The replaceable nylon inserts are available in different colors with different degrees of retention.<sup>9</sup> Moreover, resilient studs can be used to compensate implant angulations. The manufacturers recommend the inserts with dual (internal and external) flanges when the angulation between the implants is from 0 to 20 degrees or when the individual implant inclination does not exceed 10 degrees in relation to the path of insertion of the prosthesis. "Extended range" inserts have outer flanges only. These inserts are

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recommended when the angulation between the implants is more than 20 degrees or when single implant inclination exceeds 10 degrees.<sup>10,11</sup>

The placement of interforaminal implants to retain overdentures must take into account the compromised morphology of the edentulous mandible. Inclined implants are required in certain clinical circumstances, such as mandibular resorption and lingual concavities, to fit them into the remaining bone.<sup>12,13</sup> [AU: Editing okay? (1) ng the human cephalometric radiographs, the remaining alveolar bone does not align in the direction of the axial position of the implants, but instead, it appears to be retroinclined as a result of ongoing labial atrophy of the mandibular ridge after extraction of anterior teeth.<sup>14,15</sup> This atrophy frequently causes a lingual inclination of implants in the interforaminal region.<sup>12</sup> Mericske-Stern<sup>12</sup> reported that exact perpendicular position of the implants could only be detected in few patients, while the majority of individuals had a lingual or buccal inclination of the implant axis.

The retention of the prosthesis is a very important factor that usually determines patient satisfaction and guality of life.<sup>16</sup> While attachments are utilized to provide retention (resistance to removal along the path of insertion) during mastication, nonaxial forces may be transmitted to the implants.<sup>17</sup> Bending moments resulting from axial and nonaxial dislodging may induce stress concentrations that may exceed the physiologic adaptive capacity of cortical bone, leading to unwanted bone resorption and implant failures.<sup>18</sup> For an attachment to be successful, it should give adequate retention and at the same time transmit minimal stresses to the implants during displacement.<sup>17</sup> The inclination of the implants was found to affect stresses around implants<sup>19,20</sup> and retention forces<sup>21,22</sup> of stud attachments. However, the influence of implant inclination on stresses around implants during dislodgment of the attachments was not a concern. Therefore, the purpose of the present study was to investigate the effect of implant inclination on retention and peri-implant stresses of stud-retained implant overdentures during axial and nonaxial dislodgments. Two research questions were investigated: (1) will the retention of locator overdentures be affected by either implant inclination or displacement direction?; and (2) will the peri-implant strains caused by the resistance of overdentures to displacement be affected by either implant angulation or displacement direction?

## **MATERIALS AND METHODS**

#### **Experimental Setup**

Four duplicate acrylic resin models of a completely edentulous mandibular ridge were made. Two implants

(3.7 × 13 mm, TioLogic, Dentaurum) were placed in the canine areas of each model with the following degrees of lingual inclination relative to the vertical plane: 0 (model 1), 5 (model 2), 10 (model 3), and 20 degrees (model 4). The degree of lingual angulation was adjusted using a modified protractor placed on the acrylic jig<sup>19,20</sup> (Fig 1). The residual ridge and the retromolar regions of acrylic resin models were covered with 1.5-mm thickness of self-cure silicone soft liner (Permaflex, Kohler) to simulate natural mucosa.<sup>23,24</sup> The stud abutments (3.7-mm width and 3-mm gingival height) were torqued to the implants at 35 Ncm.

Four metal-reinforced experimental overdentures were constructed. Each overdenture consisted of cobalt chromium metal framework with four vertical hooks (at canine and second molar sites) and acrylic occlusion rim.<sup>23,25</sup> The resilient stud matrices were snapped on the stud abutments and attached to the experimental overdentures using self-cure acrylic resin. The light retention (pink, 1.365 Kg) male inserts were used. For each implant angulation (0, 5, 10, and 20 degrees), and dislodging condition (vertical, anterior, posterior, and lateral), 10 samples of male inserts were used (total No. of inserts = 160 [40/group]) according to the results of other investigations<sup>5,19,20,22,26</sup> to get sufficient power in the results. The inserts are used once, then discarded after each measurement and replaced by new inserts to avoid the effect of wear on peri-implant stress measurements.

Four linear strain gauges (KFG-1-120-C1-11L1M2R, KYOWA electronic instruments, Japan) were attached to buccal, lingual, mesial, and distal surfaces of acrylic resin around each implant<sup>27</sup> using a special glue (KYOWA electronic instruments). The long axis of each gauge was oriented at a right angle to the implant axis (Fig 2). The other four gauges were attached to acrylic dummy control pieces to minimize heat generation caused by loading of each model. The fine wire terminals of all gauges were attached to a ½ circuit Wheatstone bridge (Sokki Kenkyujo), and to a device interface (Tinsley) controlled by a personal computer. The computer software transformed the output voltage to microstrain data.

#### Measurements of Retention (Dislodging) Forces

Four 15-cm metal chains were connected to the hooks of the overdenture at one end and to a metal plate (5  $\times$  5 cm) at the other end.<sup>22</sup> The plate was attached to a universal testing machine (Model No. 3382, Instron Corp). Four-point vertical load was applied at 50 mm/min crosshead speed to simulate the velocity of denture displacement away from the tissue during mastication<sup>22,28</sup> (Fig 3). Maximum force required to disengage the prosthesis from the attachments in Newtons (N) was calculated by the software of the



Fig 1 (a) Model 1 (0 degrees). (b) Model 2 (5 degrees). (c) Model 3 (10 degrees). (d) Model 4 (20 degrees).



Fig 2 (above) Strain gauge installation.

Fig 3 (right) Strain measurements during vertical dislodging.

universal testing machine after adjusting the machine into tensile mode and recorded as axial (vertical retention).<sup>21,22</sup> Three types of nonaxial retention forces were measured<sup>23,25,29,30</sup>:

1. Anterior dislodgment: by connection of right and left canine chains only



Table 1         Retention Forces (N) of Different Implant Angulations and Dislodging Conditions									
	Axial (vertical) dislodging		Anterior dislodging		Posterior dislodging		Lateral dislodging		ΔΝΟΛΑ
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	P value
0° implant angulation (model I)	40.07 <sup>a</sup>	0.90	67.02 <sup>b</sup>	1.00	27.12 <sup>c</sup>	1.02	28.58 <sup>d</sup>	1.51	< .001*
5° implant angulation (model I)	30.22 <sup>a</sup>	1.07	39.08 <sup>b</sup>	1.01	20.13 <sup>c</sup>	1.03	23.25 <sup>d</sup>	1.09	< .001*
10° implant angulation (model I)	27.09 <sup>a</sup>	1.01	38.06 <sup>b</sup>	1.00	21.01 <sup>c</sup>	1.00	22.18 <sup>d</sup>	1.05	< .001*
20° implant angulation (model I)	15.09 <sup>a</sup>	1.14	20.87 <sup>b</sup>	0.23	10.16 <sup>c</sup>	1.04	11.92 <sup>d</sup>	0.89	< .001*
ANOVA P value	<.00	1*	< .001	*	< .001	*	< .00	*	

\**P* is significant at 5% level of significance. Different letters in the same row indicate significant difference between dislodging conditions (Bonferroni test, *P* < .05).

# Table 2Lateral Forces (Peri-implant Stresses, μs) of Different Implant Angulations and Dislodging<br/>Conditions

	Axial (vertical) dislodging		Anterior dislodging		Posterior dislodging		Lateral dislodging		ANOVA
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	P value
0° implant angulation (model I)	883.33 <sup>a</sup>	76.38	1,171.00 <sup>b</sup>	28.10	234.00 <sup>c</sup>	7.79	426.67 <sup>d</sup>	25.17	<.001*
5° implant angulation (model I)	495.00 <sup>a</sup>	77.94	720.00 <sup>b</sup>	77.94	136.67 <sup>c</sup>	12.58	275.00 <sup>d</sup>	27.84	<.001*
10° implant angulation (model I)	465.00 <sup>a</sup>	56.35	680.00 <sup>b</sup>	98.49	126.67 <sup>c</sup>	12.58	253.33 <sup>d</sup>	35.12	<.001*
20° implant angulation (model I)	265.00 <sup>a</sup>	56.35	413.33 <sup>b</sup>	32.15	73.33 <sup>c</sup>	7.64	156.67 <sup>d</sup>	30.55	<.001*
ANOVA P value	< .00	*	< .001	*	.004	*	<.001	*	

\*P is significant at 5% level of significance. Different letters in the same row indicate significant difference between dislodging conditions (Bonferroni test, P < .05).

- 2. Posterior dislodgment: by connection of right and left molar chains only
- 3. Lateral dislodgment: by connection of canine and molar chains on the right side only

The nonaxial dislodgment force required to disengage the prosthesis was recorded (in N) to represent anterior, posterior, and lateral retention forces. The sequence of axial and nonaxial dislodging (displacements) was randomized to avoid the effect of order of type of dislodging on stress measurement. Sequence randomization was made using random numbers generated in an Excel spreadsheet. Five measurements were recorded for all dislodgments, and the mean was used as retention forces.<sup>23,29</sup>

### **Measurements of Peri-implant Stresses**

The strain gauges were calibrated to ensure the accuracy and linearity of the measurements.<sup>31</sup> Strain measurements were made during axial and nonaxial (anterior, posterior, and lateral) dislodging. The recorded strains at mesial, distal, buccal, and lingual gauges were averaged, and the mean was used. All measurements were repeated five times, with a 5-minute recovery period to cool the gauges, and the obtained microstrains were averaged and then converted to stresses using the formula: stresses/strains = modulus of elasticity of acrylic resin.

### **Statistical Analysis**

Two-way analysis of variance (ANOVA) was utilized to compare retentive forces, and implant stresses (dependent factors) between implant inclinations and dislodging directions (independent factors) followed the Bonferroni post hoc test. The multiple linear regression model was used to test the relation between peri-implant stresses (dependent variable) and other confounding variables (implant inclination, dislodging direction, and retentive forces). The level of significance was adjusted at P < .05.

# RESULTS

Retention forces (N) and peri-implant stresses ( $\mu$ s) of different implant angulations and dislodging directions are presented in Tables 1 and 2, respectively. There was a significant difference in retention forces and implant stresses between groups. The highest retention and stresses were noted with 0-degree inclination, followed by 5 and 10 degrees, and the lowest values were noted with 20 degrees. Multiple comparisons of retention and implant stresses between implant inclinations are presented in Figs 4 and 5, respectively. No significant differences in retention and implant stresses between 5- and 10-degree inclinations were noted. There was a



**Fig 4** Multiple comparison of retentive forces between each two groups. Lines connecting bars indicate no significant difference between groups (Bonferroni test, P > .05).



**Fig 5** Multiple comparison of lateral forces between each two groups. Lines connecting bars indicate no significant difference between groups (Bonferroni test, P > .05).

significant difference in retention and implant stresses between dislodging directions. The highest retention and implant stresses were noted with anterior dislodging, followed by vertical dislodging, then lateral dislodging, and the lowest values were noted with posterior dislodging.

In the multiple regression analysis, dislodging direction (Coeff = -48.284; SE = 13.852; t = -3.486; P < .001; 95% CI = -76.201 to -20.367), and retentive forces (Coeff = 20.893; SE = 1.541; t = 13.559; P < .001; 95% CI = 17.787 to 23.998) were significantly correlated with change in implant stresses around implants (Table 3). The implant inclination failed to show a significant effect on the amount of implant stresses. Consequently, the final model contained dislodging directions and retentive forces (Table 4). The effect of retentive force was such that, for every 1-N increase in retention forces, there would be an increase in the periimplant stresses by 19.17  $\mu$ s (SE = 1.111; *t* = 17.256; *P* < .001; 95% CI = 16.941 to 21.418). The effect of dislodging direction on predicted implant stress values is shown in Table 5. For vertical dislodging, the implant stresses increased by 527.083 us (SE = 57.122; t = 9.227; P < .001; 95% CI = 411.962 to

# Table 3Multiple Linear Regression Analysis of All ConfoundingVariables in Relation to Lateral Forces

Variable	Coefficient B	Standard error (SE)	t	Р	95% confidence interval (Cl)
Implant inclination	27.322	17.310	1.578	.122	-7.563 to 62.208
Dislodging condition	-48.284	13.852	-3.486	< .001*	-76.201 to -20.367
Retentive forces	20.893	1.541	13.559	< .000*	17.787 to 23.998

#### Table 4 Multiple Linear Regression Analysis Including Dislodging Condition and Retention Forces Only

Variable	Coefficient B	Standard error (SE)	t	Р	95% Confidence interval (Cl)
Dislodging condition	-55.404	13.312	-4.162	< .001*	-82.216 to -28.592
Retentive forces	19.179	1.111	17.256	< .001*	16.941 to 21.418

# Table 5 Multiple Linear Regression Analysis Including Levels of Dislodging Condition

Variable	Coefficient B	Standard error (SE)	t	Р	95% Confidence interval (Cl)
Vertical dislodging	527.083	57.122	9.227	< .001*	411.962 to 642.205
Anterior dislodging	846.000	80.782	2.711	.010*	56.194 to 381.806
Posterior dislodging	143.417	80.782	-4.759	< .001*	547.223 to -221.611
Lateral dislodging	298.167	80.782	-3.084	.004*	-411.973 to -86.361

642.205). For anterior dislodging, the implant stresses increased by 846.00 μs (SE = 80.782; t = 2.711; P = .010; 95% CI = 56.194 to 381.806). For posterior dislodging, the implant stresses increased by 143.417 μs (SE = 80.782; t = -4.759; P < .001; 95% CI = 547.223 to -221.611). For lateral dislodging, the implant stresses increased by 298.167 μs (SE = 80.782; t = -3.084; P = .004; 95% CI = -411.973 to -86.361).

# DISCUSSION

During function with an implant-retained overdenture, loads are transmitted to alveolar bone surrounding the implants. Bending moments resulting from nonaxial overloading of the implants may result in stress concentrations exceeding the physiologic adaptive capacity of cortical bone, leading to crestal bone loss and implant failures.<sup>18</sup> It is difficult to measure strains at the implant surface directly, as it is embedded in the acrylic resin. Strain gauges were attached to the acrylic resin surface around each implant, as stresses are more concentrated in the coronal area of the implants.<sup>32</sup> Thus, strain measured on the acrylic surface around the implant could be used as an indicator of moments applied to the implants.<sup>33</sup> The strains were attached to the buccal, lingual, mesial, and distal sides of each implant to provide accurate and conclusive measurement of peri-implant strain. The gauges were oriented as closely as possible to the implants to record the acrylic resin deformation around the implants accurately. In this study, vertical, anterior, posterior, and lateral dislodgments were performed, as during function, implant overdentures are moved away from the tissues in several dislodging directions such as vertical, oblique, and rotational directions.<sup>34</sup> The resistance of vertical dislodging (known as retention) is an important factor in achieving patient satisfaction with implant-retained overdentures.<sup>35</sup> The anterior dislodging is similar to patient movement of the overdenture by exerting upward pressure opposite the attachments. Posterior displacement often occurs in a clinical setting when posterior extension saddles of the denture move away from the tissues during mastication by action of mucosal rebound or sticky food.<sup>36,37</sup> Lateral dislodgment simulates patient removal of the denture from one side.

In this study, the lowest retention was noted at 20-degree angulation during posterior dislodging  $(10.16 \pm 1.04 \text{ N})$ . This value still remains higher than the accepted retention values for implant overdentures that are sufficient to obtain high patient satisfaction (8 N).<sup>6,37</sup> The highest retentive force was observed with 0 degrees, followed by 5 and 10 degrees, and the lowest forces were noted with 20 degrees. Similarly, Al-Ghafli et al<sup>38</sup> concluded that implant angulations negatively affect retention of stud-retained implant overdentures. In contrast, Rabbani et al<sup>34</sup> noted an increase in the retention of stud inserts by the increase in the degree of mesial implant inclination. In this study, the reduction of retention with increased implant inclination may be attributed to the lingual inclination of the implants, which eliminates undercut on the buccal side, allowing the nylon inserts to disconnect the abutments more easily overall.<sup>10</sup> The increased retention forces with 0-degree inclination may be attributed to the resiliency and the double frictional flanges of male inserts, which permit

slow disengagement from the stud abutments during dislodging when the implants are inserted parallel to each other.

The highest retention was observed during anterior displacement, followed by vertical displacement, then lateral displacement, and the lowest forces were noted with posterior displacement. The increased retention with anterior dislodging may be attributed to the lingual inclination of the implants, which creates lingual undercuts in the stud abutments. The patrix insert would have to escape a greater undercut on the lingual side. The decreased retention with posterior dislodging may be attributed to the lingual implant inclination, which is opposite the direction of posterior dislodging forces. Therefore, rapid disengagement of nylon inserts occurs due to minimal friction with stud matrices. In line with this explanation, the author<sup>22,39</sup> found that increased implant angulation recorded the highest retention forces when implants are inclined labially and distally. These findings signify the importance of studying the retention forces regarding the direction of implant angulation.

The highest peri-implant stresses were observed with 0 degrees, followed by 5 degrees and 10 degrees, and the lowest forces were noted with 20 degrees. The increased stresses with 0-degree inclination may be due to frictional contact retention of the Locators, which comes from the slightly large diameter of the nylon insert and the small inner diameter of the abutment.<sup>8</sup> The dual friction of the nylon inserts provides slight hinge movement, thus increasing stress transmission to the implants during dislodging.<sup>40</sup> When implants are inserted vertically, the matrix abutment is aligned parallel to the path of removal of the stud patrix; retention is derived evenly from all the undercuts. Therefore, the stud attachments did not disengage easily and transmitted high lateral stresses to the implants. The decreased stresses with increased implant inclination (20 degrees) may be attributed to rapid disengagement of nylon inserts that occurs due to minimal friction with stud matrices during dislodging.

The highest implant stresses were observed with anterior dislodging, and the lowest stresses were observed with posterior dislodgment. This could be attributed to the increased retention forces during anterior dislodging, which cause slow disengagement of male inserts from stud abutments, thus transmitting more stresses to the implants. In agreement with this observation, Yang et al<sup>17</sup> reported increased peri-implant stresses during anterior dislodging as the inclinations increased, especially with increased retentive force of the attachment. In contrast, the reduced retention forces caused by rapid disconnection of the male insert from the abutment may be responsible for reduced peri-implant stresses during posterior dislodging. In a clinical setting, posterior dislodgment occurred when the posterior extension bases of the overdentures moved away from tissues during function or eating sticky food.<sup>37</sup> This movement is usually associated with implant loading and lower patient satisfaction when implants are inserted vertically.<sup>33</sup> Therefore, increased lingual implant inclination may be advantageous in terms of reduced stresses on the implants during function compared with parallel implants. Also, the patients may be advocated to remove the overdenture by applying upward pressure on the distal extension saddles of the overdentures when implants are inclined lingually to enhance rapid overdenture removal with minimal stress transmission to the implants, especially for individuals with decreased manual dexterity.

Ideal attachment should give increased retention and at the same time transmit minimal stresses to the implants during recurrent displacement when implants are inserted vertically or inclined.<sup>17</sup> In this study, periimplant stresses had a positive correlation with change in retentive forces. The higher the retention (resistance to dislodging) forces, the more the transferred stresses to the implants. A similar finding was also observed in other reports.<sup>17,41</sup> The interesting finding of this study is that, for every 1-N increase in retention forces, there was an increase in the peri-implant stresses by 19.17 µs. Therefore, increased retention of an implant-retained overdenture is not absolutely advantageous, because it is also associated with an increase in the stresses transmitted to the implants.<sup>41</sup>

Although in vitro studies differ from clinical studies, they allow standardization of the tests by excluding oral conditions, and therefore, they provide important information.<sup>42</sup> However, the absence of saliva is considered a limitation of the present study, as saliva may influence the friction between the inserts and abutments of stud connectors, which could affect the retentive force.<sup>5</sup> Furthermore, vertical and obligue dislodging forces only were simulated. However, the dynamic nature of overdenture movement in the complex environment of the oral cavity has proven challenging to replicate in a laboratory setting. Moreover, implants are angulated to the path of prosthesis insertion in the sagittal plane only. In the clinical setup, lingual inclination may be associated with mesiodistal implant inclination in the coronal plane. Clinical studies are required to investigate the retention and patient satisfaction of stud attachments used to retain mandibular overdentures to lingually inclined implants.

### CONCLUSIONS

Within the limits of this investigation, it could be concluded that retention forces and peri-implant stresses decreased as lingual implant inclination increased during axial and nonaxial dislodging of stud-retained implant overdentures. Peri-implant stresses were significantly correlated with dislodging direction and retentive forces.

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