Strains around distally inclined implants retaining mandibular overdentures with Locator attachments: an *in vitro* study

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PURPOSE. The aim of the present study was to evaluate, by means of strain gauge analysis, the effect of different implant angulations on strains around two implants retaining mandibular overdenture with Locator attachments. **MATERIALS AND METHODS.** Four duplicate mandibular acrylic models were constructed. Two implants were inserted in the canine regions using the following degrees of distal inclinations: group I (control); 0°, group II; 10°, group III; 20°, and group IV; 30°. Locator pink attachments were used to connect the overdenture to the implants and Locator red (designed for severely angled implants) was used for group IV (group IV_{red}). For each group, two linear strain gauges were attached at the mesial and distal surfaces of the acrylic resin around each implant. Peri-implant strain was measured on loading and non-loading sides during bilateral and unilateral loading. **RESULTS.** For all groups, the mesial surfaces of the implants at loading and non-loading sides experienced compressive (negative) strains, while the distal implant surfaces showed tensile (positive) strains. Group IV showed the highest strain, followed by group III, group II. Both group I and group IV_{red} showed the lowest strain. The strain gauges at the mesial surface of the loading side recorded the highest strain, and the distal surface at non-loading side showed the lowest strain. Unilateral loading recorded significantly higher strain than bilateral loading. **CONCLUSION.** Peri-implant strains around two implants used to retain mandibular overdentures with Locator attachments increase as distal implant inclination increases, except when red nylon inserts were used. ***[J Adv Prosthodont 2016;8:116-24]***

KEY WORDS: Strain; Inclined implants; Locator; Overdentures

INTRODUCTION

The implant-retained overdenture has become an accepted and predictable treatment modality for edentulous patients because of its significant improvement in retention and stability.[1] According to the McGill consensus statement[2] on overdentures, such prosthesis should become the minimum standard of care for the edentulous mandible. Several attachment systems may be used to retain overdentures to the implants, such as ball anchors, bars, magnets, and telescopic crowns.[3]

A prefabricated, self-aligning attachment system that maintains both vertical and hinge resiliency has recently been introduced and is called a Locator attachment.[4] In this unique design of the Locator, the patrix (male) is the replaceable nylon insert on the undersurface of the overdenture. The matrix (female) is, accordingly, the overdenture abutment on the implant.[5] The Locator system has been promoted as an alternative to ball attachments, especially when the interarch distance is inadequate[6] to avoid the denture base deformation and fracture.[7] Locator attachments provide the ability to control the degree of retention by changing their retentive elements.[4] The Locators have extra advantages in complex cases, as they can compensate for severe angle misalignment (i.e. a divergence of up to 40

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degrees between the implant and the connector system).[8]

During mastication, loads are transferred to alveolar bone surrounding the implants retaining overdentures. It is important not to cause excessive loads on the implants[9] because it has been reported that excessive load may cause peri-implant bone loss through the induction of bone microdamage.[10,11] A key factor for success or failure of dental implants is the manner in which stress is transferred to peri-implant bone.[12]

With respect to stress distribution, ideal insertion of the implants is known to be parallel to each other, parallel to the long axis of occlusal loading, and perpendicular to the occlusal plane.[13,14] However, an inclined implant is required in certain clinical circumstances, e.g., to fit the implants into the remaining bone in case of mandibular resorption or lingual concavities or to optimize the anteroposterior spread of implants.[15] Walton *et al.*[16] reported that there was a tendency for less experienced surgeons to place implants incorrectly so that the implants diverged from each other (with a distal inclination) in the frontal plane.

The influence of different types of attachments on peri-implant stress has been sufficiently investigated.[3,9,17-21] However, few studies reported the effect of implant inclination on the stress around implants retaining mandibular overdentures.[19,22-24] Two of the previous studies[19,23] were concerned about using the photoelastic stress analysis for the evaluation of peri-implant stresses around 3 implants inserted in the interforaminal areas to retain mandibular overdentures with different attachments (bars, ball, Locator and ERA attachments). Another study[22] examined, by means of finite element analysis, the level and distribution of peri-implant bone stresses around mandibular two-implant overdentures with ball attachment system. In a recent study,[24] the authors used photoelastic stress analysis for evaluating the stress distribution in mandibular bone surrounding 2 implants retaining mandibular overdenture with bar-clip attachments.

Al-Ghafli *et al.*[25] investigated the effect of different degrees of mesial inclinations of 2 implants retaining overdentures with Locator attachments. They concluded that implant angulations negatively affect attachment retention. Similarly, Rabbani *et al.*[26] evaluated the effect of cyclic disengagement on the retentive force and wear patterns of three Locator inserts (blue, pink, and clear) placed on mesially angulated implants. They noted a rapid decrease in the retentive force after 720 cycles for all three inserts. Stephens *et al.*[27] evaluated the effect of different degrees of distal implant inclination on the retention of two Locator blue inserts before and after *in vitro* simulation of 3 to 5 years of use. They found that the retention of Locator pairs was not impaired by inter-implant divergence of up to 20 degrees. However, there has not been enough information to fully investigate the effect of implant angulation on the strains around implants connected to the overdentures with Locator attachments.

Accordingly, the aim of the present study was to evaluate of the effect of different implant angulations on peri-implant strains under the Locator-retained mandibular overdenture using strain gauge method. The hypothesis was that there would be no significant difference in strains around implants inserted at different degrees.

MATERIALS AND METHODS

Four acrylic models were constructed by duplicating a mandibular edentulous stone model (without undercuts) using heat cured acrylic resin.[28,29] The base of each acrylic resin model was trimmed parallel to the anterior alveolar residual ridge. Each model was placed on the table of a parallometer milling device (BF 2, Bredent, GmbH&Co, KG, Senden, Germany). The drills of the parallometer milling device were held perpendicular to the occlusal surface of anterior alveolar residual ridge of each model.

Two recesses were prepared at the canine regions using consecutive drills held at the following degrees of distal inclinations (away from midline): Model I (control); vertical to the residual ridge, Model II; 10°, Model III; 20°, and Model IV; 30°. The distal drill inclination was controlled using a conventional transparent plastic semicircular protractor by placing it on the occlusal surface of the anterior alveolar residual ridge of each model (Fig. 1) to measure angles in degrees. Each implant recess inclination was established by pivoting the table of the milling device mesio-distally to match the long axis of each drill to the degree of the proposed implant inclination. Distal implant inclinations were completed by inserting two 3.7 × 13 mm laboratory implants (TioLogic, Dentaurum, Ispringen, Germany) in the prepared recesses with the help of Locator abutments that was screwed in the internal hex of the implants (Fig. 2).

Fig. 1. Controlling the degree of distal implant inclination using a conventional transparent plastic semicircular protractor.

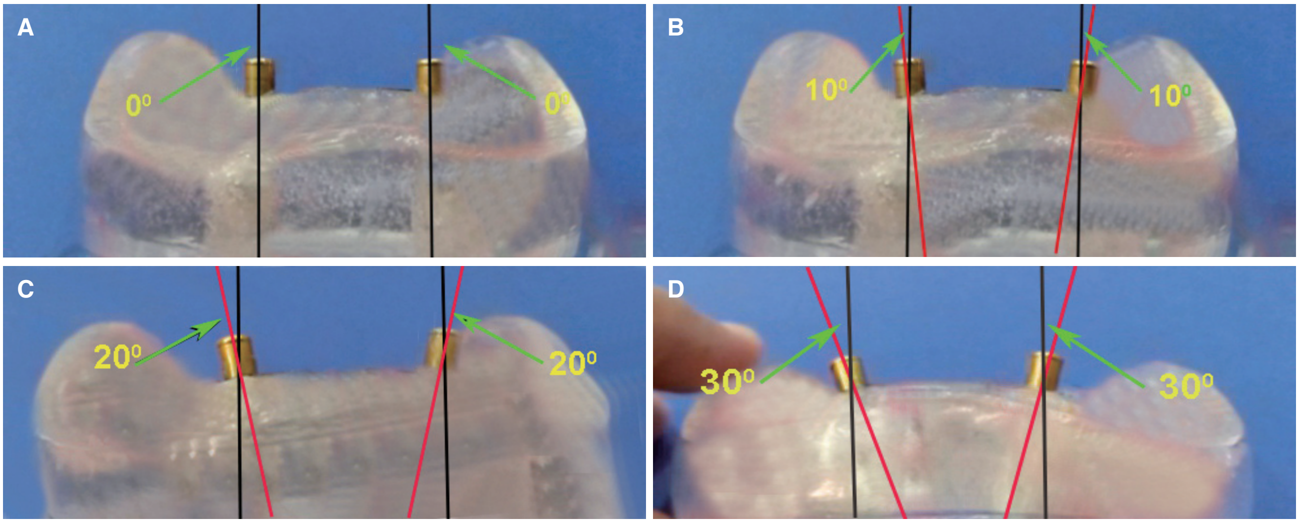

Fig. 2. (A) Group I (0°) implant inclination, (B) Group II (10°) implant inclination, (C) Group III (20°) implant inclination, (D) Group IV (30°) implant inclination.

For each model, an approximately 1.5-mm-thick layer of autopolymerized resilient silicone soft lining material (Softliner®, Promedica, GmbH, Neumünster, Germany) was used to mimic resilient edentulous ridge mucosa.[18,30] Five mandibular record blocks were constructed over each model (total record blocks = 20). The occlusal plane of the record blocks was adjusted to the level of between the upper and middle third of the retromolar pad.[31] Locator pink inserts (low retention; 1.365 g, TioLogic, Dentaurum, Ispringen, Germany) were used to connect the overdentures to the implants (groups I to IV) and Locator red inserts (extra low retention; 680 g, designed by the manufacture without internal frictional flange for increased implant angulations) were used for 30° implant angulation (group IV_{red}).

The silicone soft liner material was removed from the implants using a sharp scalpel. For each group, two linear strain gauges (KFG-1-120-C1-11L1M2R; KYOWA electronic instruments CO., Ltd., Tokyo, Japan; resistance 119.6 ± 0.4 % Ω; gauge length: 1 mm; gauge factor: 2.08 ± 1.0 %) were attached using adhesive resin (CC-33A, EP-34B., KYOWA electronic instruments Co., Ltd.), at the mesial and distal surfaces of the acrylic resin around each implant.[32] The gauges were labelled as follows; RD: distal side of the implants at loading side, RM: mesial side of the implants at loading side, LM: mesial side of the implants at non-loading side, and LD: distal side of the implants at non-loading side (Fig. 3). All gauges were positioned on the crest of the ridge in a mesiodistal direction perpendicular to the long axis of each implant.

The strain gauge lead wires (100 cm in length) were properly isolated and secured to the buccal surface of each model in specially prepared channels using a quick-set adhesive to avoid any movement of the wires that may affect the accuracy of reading. For each model, acrylic dummy specimens were prepared as a control to receive four strain gauges in order to control any thermal changes resulting from loading. Free ends of the lead wires of the active (test) and dummy (control) strain gauges were twisted together and connected to form a half-circuit Wheatstone bridge (CSW-5A-05 switching box, Tokyo Sokki Kenkyujo Co., Ltd., Tokyo, Japan). The other half of the bridge was linked to a digital Strain meter (Tinsley and Co. Ltd., Werndee Hall, London, H. Model 8692), which electrically amplified the small signals of the strain gauge and converted them into a voltage output.

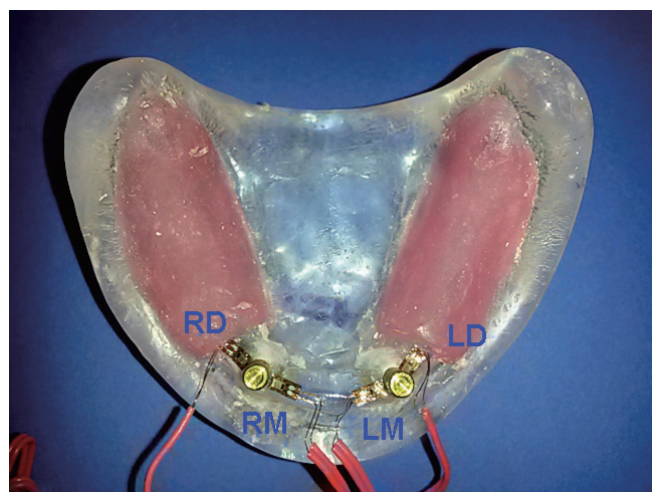

Fig. 3. The strain gauge positions around the implants.

The strain gauges were calibrated to determine the relationship between the load applied and the strain signals received from the strain meter and to verify the repeatability of the readings of the gauges. A load ranged from 10 to 60 N was applied on the record block using a loading device.[33]

Each model was put on the compression grip of the universal testing machine and secured in position with the occlusal plane in a horizontal position. A digitized universal testing machine (LLOYD LRX, LLOYD instruments Ltd., Fareham, Hampshire, UK) was used to apply a vertical static load both unilaterally and bilaterally.[9,32,33] For bilateral load application, a metal bar (6 cm in length, 1 cm in width, and 2 mm in thickness) was positioned in the region of the first molars on the occlusion rim between the right and left denture bases. The forces were delivered to the center of the metal bar using a loading pin (applicator) (Fig. 4). For unilateral load application, the right side of the overdenture was considered the loading side, while the left side was considered the non-loaded side. The point of load application was on the central fossa of the 1st molar and was notched with a diamond bur (Fig. 5). This was done for reproducibility, accommodating the tip of the loading pin on the same location (notch), and preventing slippage of the pin[32,33] All measurements were repeated 5 times for each overdenture, allowing at least 5 minutes for heat dissipation, and the mean of the recorded microstrains was calculated.

Two-way ANOVA was used to compare the recorded microstrain values between different groups (I, II, III, IV, and IV_{red}) and between different sites of measurements (RD, RM, LM, and LD), followed by post hoc (Bonferroni) test for multiple comparisons. To compare the recorded microstrain values between loading applications, paired sample t test was used. *P* value was significant if it was less than 0.05 at confidence interval 95%. The SPSS statistical package for social science version 22 (SPSS Inc., Chicago, IL, USA) was used for data analysis.

RESULTS

Twenty mandibular record blocks were calculated to yield a power of 98% with a type I error of 0.05 (One way ANOVA with (μ) strain is the independent variable) using a computer program (Power and precision version 3, 2007, Biostat, Englewood, USA) for a statistically significant minimum difference of 32 in mean (μ) strain between groups (effect size = 1.28 and SD = 30). For all groups, mesial peri-implant sites at loading and non-loading sides experienced compressive (negative) strains, while distal implant sites showed tensile (positive) strains.

Comparisons of all microstrain values between groups, between the sites of strain gauges, and between load applications are presented in Table 1, Table 2, and Table 3, respectively. Significant differences were detected between groups, the sites of strain gauges, and load applications (*P* = .00). Group IV recorded the highest strain, followed by group III, group II, and both group I and IV_{red} recorded the lowest strain (Table 1). RM sites recorded the highest strain, followed by RM, and LM and LD recorded the lowest strain (Table 2). Unilateral loading recorded a significantly higher strain than bilateral loading (Table 3).

Comparisons of peri-implant strains between groups are presented in Table 4 and Table 5. At different sites of strain gauges (RD, RM, LM and LD) during unilateral and bilateral load applications, group IV demonstrated the highest peri-implant strain, followed by group III and group II. The lowest strain was recorded at group I and group IV_{red}

Fig. 4. Bilateral load application.

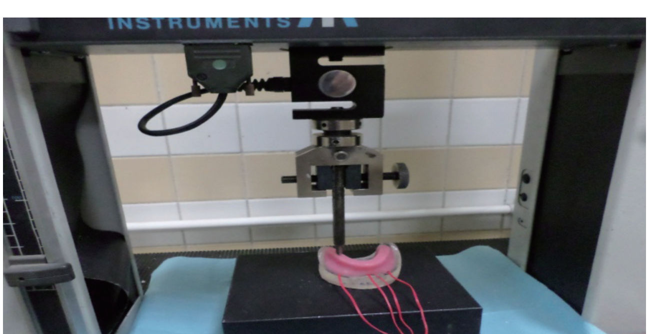

Fig. 5. Unilateral load application.

Table 1. Comparison of total microstrains between groups

Group	Mean	St. error	ANOVA *P* value	Post hoc test (Bonferroni)
I	-31.875	6.685		A
II	-105.250	6.685		B
III	-147.925	6.685	.00*	C
IV	-220.750	6.685		D
IV_{red}	-30.375	6.685		A

* *P* is significant at 0.05 level of significance. The different upper case letters indicate significant differences between groups.

without significant differences. As the angle of implant inclination increases, the peri-implant strains also increase at different sites of strain gauges except when red nylon insert was used

Comparisons of peri-implant strains between sites of strain gauges are presented in Table 4 and Table 5. During unilateral load application, the highest strain was recorded at RM for all groups and the lowest strain was noted at LD. During bilateral load application, the highest strain was recorded at RM for all groups (except group II), and the lowest strains were recorded at LM for groups I and IV_{red} and at LD for groups II, III, and IV.

Table 2. Comparison of total microstrains between sites of strain gauges

Group	Mean	St. error	ANOVA *P* value	Post hoc test (Bonferroni)
RD (right distal)	472.100	5.979	.00*	A
RM (right mesial)	-784.400	5.979		B
LM (left mesial)	-299.400	5.979		C
LD (left distal)	182.760	5.979		D

* *P* is significant at 0.05 level of significance. The different upper case letters indicate significant differences between sites.

Table 3. Comparison of recorded microstrain values between unilateral and bilateral load application

	Mean	St. error	Paired samples t test
Unilateral load application	-144.870	4.228	.00*
Bilateral load application	-69.600	4.228	

* *P* is significant at 5% level.

Table 4. Comparison of peri-implant stain between groups and between sites of strain gauges during bilateral load application

Group	RD (right distal) (X ± SD)	RM (right mesial) (X ± SD)	LM (left mesial) (X ± SD)	LD (left distal) (X ± SD)	2-way ANOVA
I	$99.00 \pm 2.23^{A,a}$	$-156.00 \pm 2.23^{A,b}$	$-89.00 \pm 4.18^{A,c}$	$134.00 \pm 2.23^{A,a}$	.00*
II	$169.00 \pm 220.32^{B,a}$	$-246.00 \pm 14.74^{B,b}$	$-304.00 \pm 29.66^{B,c}$	$50.00 \pm 10.60^{B,d}$	.00*
III	$961.00 \pm 66.93^{C,a}$	$-1220.00 \pm 57.00^{C,b}$	$-408.00 \pm 13.03^{C,c}$	$120.00 \pm 15.81^{C,d}$	.00*
IV	$1048.00 \pm 5.70^{D,a}$	$-1428.00 \pm 28.19^{D,b}$	$-309.00 \pm 4.18^{D,c}$	$193.00 \pm 2.73^{D,d}$	.00*
IV_{red}	$94.00 \pm 4.18^{A,a}$	$-147.00 \pm 7.58^{A,b}$	$-84.00 \pm 4.18^{A,c}$	$131.00 \pm 2.23^{A,d}$	.00*
2-way ANOVA (P)	.00*	.00*	.00*	.00*	

X; mean, SD; standard deviation, LSD; least significant differences. The different upper case letters indicate significant. The different upper case letters indicate significant differences between groups (Bonferroni, *P* < .05). The different lower case letters indicate significant differences between sites of strain gauges (Bonferroni, *P* < .05). * *P* is significant at 5% level of significance.

Table 5. Comparison of peri-implant stain between groups and between sites of strain gauges during unilateral load application

Group	RD (right distal) (X ± SD)	RM (right mesial) (X ± SD)	LM (left mesial) (X ± SD)	LD (left distal) (X ± SD)	2-way ANOVA
I	$98.00 \pm 5.70^{A,a}$	$-313.00 \pm 8.36^{A,b}$	$-119.00 \pm 6.51^{A,c}$	$91.00 \pm 4.18^{A,a}$	.00*
II	$653.00 \pm 42.66^{B,a}$	$-936.00 \pm 39.11^{B,b}$	$-487.00 \pm 5.70^{B,c}$	$259.00 \pm 6.51^{B,d}$	.00*
III	$714.00 \pm 23.02^{C,a}$	$-1220.00 \pm 75.82^{C,b}$	$-485.00 \pm 3.53^{C,c}$	$354.60 \pm 13.53^{C,d}$	.00*
IV	$792.00 \pm 4.47^{D,a}$	$-1872.00 \pm 25.64^{D,b}$	$-596.00 \pm 41.59^{D,c}$	$406.00 \pm 5.47^{D,d}$	.00*
IV_{red}	$93.00 \pm 4.47^{A,a}$	$-306.00 \pm 8.94^{A,b}$	$-103.00 \pm 2.74^{A,c}$	$89.00 \pm 2.23^{A,d}$	.00*
2-way ANOVA (P)	.00*	.00*	.00*	.00*	

X; mean, SD; standard deviation, LSD; least significant differences. The different upper case letters indicate significant differences between groups (Bonferroni, *P* < .05). The different lower case letters indicate significant differences between sites of strain gauges (Bonferroni, *P* < .05). * *P* is significant at 5% level of significance.

For groups I and IV_{red}, bilateral loading showed higher association with increased strains than unilateral loading at RD and LD sites, and unilateral load showed higher strains than bilateral load at RM and LM. For groups II, III and IV, unilateral loading showed higher association with strain increase than bilateral loading at the majority of the strain gauge sites.

DISCUSSION

Distal implant inclination was performed in the present study after referring to the study of Walton *et al.*[16] reporting that less experienced surgeons had a significantly greater tendency to place implants incorrectly so that the implants diverged from each other in the frontal plane (with a distal inclination). This distal implant inclination was also used in other studies concerned with the evaluation of peri-implant stresses[19,22-24,34] and retention forces[27,35] of attachment used with angulated implants to retain overdentures.

The following degrees of implant inclination were used: 0°, 10°, 20° and 30°. Similar degrees of implant inclinations were also used in other studies[23,36,37] evaluating the effect of different implant inclinations on peri-implant stresses and retention of overdenture attachments. The degree of distal inclination was controlled using a conventional transparent plastic semicircular protractor, a procedure similar to a previous study[38] in which the author analyzed the influence of implant inclination on marginal bone loss for freestanding, implant-supported fixed partial dentures. In the study, the mesio-distal inclination of the implants, in relation to a vertical axis perpendicular to the occlusal plane, was measured with a protractor.

It was assumed that the strain measured on the bone surface could represent the stress introduced to the bone.[18,39] Thus, two strain gauges were attached to the mesial and distal sides of the acrylic resin surface around each implant. The double frictional flange of the male nylon inserts with the locator abutments provides limited hinge movement,[4] thus transmitting more stress to the implants during posterior loading.[23] When the implants were angled and received perpendicular force on the overdenture occlusal plane, they tended to move in an inclined manner, so stress concentration occurred along the mesial and distal faces of each implant.[24] The use of 2 strain gauges around each implants to measure the strain around the implants was also mentioned in other studies.[32,33]

In this study, vertical (axial) static loads were applied bilaterally to the central fossae of 1st molars. This is in agreement with Tokuhisa *et al.*,[18] who mentioned that occlusal force tended to be concentrated around the molar region where the denture showed the largest movement. The load was applied bilaterally to reproduce centric occlusion *in vivo*. The load was also applied unilaterally to reproduce unilateral chewing on the working side. The red insert was used with 30°-inclined implants as it was designed for excessive implant angulation, while the other inserts (blue, pink, and clear) could be used for small implant inclinations up to 20 degrees between implants, as recommended by the manufacturer.[8,27]

Group IV (30°, pink) demonstrated the highest peri-implant strain. In agreement with this finding, several biomechanical studies[22,24,40,41] also reported an increase in peri-implant stress with angled implants compared to vertically oriented implants. Watanabe *et al.*[41] reported that, with angled implants, the force was not directed toward the long axis of the implant, causing an uneven distribution of the load, which resulted in an increase of the stress magnitudes. Hong *et al.*[22] found that, during bilateral or unilateral load application on the implants used to retain overdentures by ball attachments, the periimplant bone stress was the greatest around distally inclined implants (15°) and the lowest around buccally inclined implants (15°). The increased peri-implant strain with Locator attachments, used to retain mandibular overdentures to interforaminal implants inserted with different degrees of inclinations, was in line with the results of other studies.[9,23,36] In another study,[36] Locator blue was associated with increased retentive and lateral forces on the implants compared to ball anchors and magnets, especially with increased implant inclination (up to 30°).

The increased strain with Locator attachments may be attributed to the mode of retention of the Locator attachments, which is frictional contact that arises from a dimensional misfit between the slightly oversized nylon male insert and the smaller diameter of the inner ring of the female abutment.[42] In clinical situations, the increased implant angulation may result in increased magnitude of micromotions around the 2 unsplinted implants. If these micromotions exceed 100 μm, they may result in greater bone turnover.[43] The high strain values at the bone/implant interface with higher degrees of implant inclination are not desired, since they may cause bone loss through the induction of bone microdamage.[10,11]

Group IV_{red} (30°, red) showed the lowest strain when used on severely angled implants. This may be attributed to the absence of internal frictional flange of the red nylon insert. On the other hand, all pink nylon inserts have double (internal and external) frictional flanges that limit the hinge movement (8°),[4] thus transmitting more stress to the implants than red inserts[23] during posterior loading.

In the present study, all mesial peri-implant sites experienced compressive (negative) strains, while distal implant sites showed tensile (positive) strains. The residual ridge morphology might be responsible for the obtained stress pattern. The residual ridge had an upward slope towards the ramus. This might have caused a mesial shift of the denture base when the vertical force was applied on the first molar area.[44] The nylon male element of the Locator attachments prevented the separation of the denture from the implants by the effect of the double frictional flanges, thereby transmitting the force in a mesial direction to the inclined implants. The mesial movement of the distally inclined implants resulted in the compression of the acrylic resin on the mesial surface of the implants, while the distal surface of the implants was subjected to tensile strains.

The mesial side at the loading side was associated with the greatest strain. Again, the forward (mesial) shift of the mandibular denture base upon posterior load application could be responsible for the high strain on the mesial side of the loading side, as described previously. The mesial movement of the distally inclined implants compressed the acrylic resin mesially to the implants, resulting in a greater strain mesial to the implants surface arising from the compression resistance of the acrylic resin.[24] In contrast, Pigozzo *et al.*[24] reported that angled implants tended to move in an inclined manner when they received a perpendicular force on the overdenture occlusal plane. Therefore, stress concentration occurred along the distal surface of the implant. Also, Federick and Caputo[19] found higher stress with the distal side of the inclined implants (divergently inclined 17° from midline) used to retain overdentures with a bar and distal resilient cap attachments. Distal side of the non-loading side was associated with the lowest strain. Similarly, Hong *et al.*,[22] found that stress values obtained from all inclined implants inserted in the canine region were lower in the non-loading side.

The increased strains with inclined implants became more evident with unilateral loading than bilateral loading. This may be due to the higher shifting tendency of the denture base during unilateral loading than bilateral loading. In the bilateral loading, the denture may rotate around the fulcrum line passing between the implants placed in the canine areas and, due to the hinge movement of the Locator attachments, the loads may be absorbed by the silicone mucosa.

The major shortcoming of the *in vitro* stress analysis methods is the use of materials that frequently fail to simulate the nature of living bone regarding mechano-biology and osseointegration.[45] Therefore, the results of this study are only descriptive. Future biomechanical studies are recommended to test the effect of different degrees of mesial, buccal, and lingual implant inclination on peri-implant stress around 2-implant overdentures retained by Locator attachments. Also, clinical research is still required to determine the influence of different implant angulations on peri-implant tissue under these overdentures.

CONCLUSION

Within the limitation of this *in vitro* strain gauge analysis, peri-implant strain around 2 implants used to retain mandibular overdentures with Locator attachments increases as the angle of distal implant inclination increases, except when red nylon inserts (without internal frictional flange) were used. If the implant displays high degree of inclination, it is recommended to use nylon inserts designed for angled implants (red inserts) to minimize stress transfer to the peri-implant region.

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