Abstract: This study aimed to evaluate the peri-implant strain around mesially inclined implants used to retain mandibular overdentures with Locator resilient attachments. Four mandibular edentulous acrylic resin models received two implants in the canine areas with 0°, 5°, 10°, and 20° mesial inclinations. Overdentures were connected to the implants using Locator attachments. Pink nylon inserts (light retention) were used for all implant inclinations, and red inserts were used for 20° inclination (20°red). Four strain gages were bonded on the mesial (M), distal (D), buccal (B), and lingual (L) surfaces of each implant. Peri-implant strains were measured during bilateral and unilateral loading. The 20° inclination showed the highest strain, followed by 10° and 5°, and both 0° and 20°red presented with the lowest strain. Site D was associated with the highest strain, followed by M, B, and L, which showed the lowest strain values. Unilateral loading and the loading side presented with significantly higher strain values than bilateral loading and the nonloading side, respectively. Hence, in this study, strains around the two-implant-retained overdentures with Locator attachments increased with increases in mesial implant angulation, except when red male inserts were used.

Keywords: implant inclination; stresses; overdentures; Locator.

Introduction

The two-implant overdenture is not the gold standard of implant therapy according to McGill (1) and York (2); instead, it is the minimum standard required for most people, considering the masticatory performance, patient satisfaction, and cost of treatment (3,4). The commonly used attachments, including studs, bars, magnets, and telescopic crowns, for connecting the denture to the implants offer different biomechanical features (3,5). A relatively recent attachment that has become increasingly popular is the Locator attachment. Locators have a low profile compared with ball anchors and can be used in patients with limited inter-arch distance to reduce both denture base deformation and fracture (6). Locators are also resilient and self-aligning and have different degrees of retention values and built-in angulation compensations. In addition, the repair and replacement of these attachments is simple and easy (7,8). Furthermore, Locator attachments are associated with favorable clinical and radiographic peri-implant outcomes (9,10).

Insertion of implants parallel to each other and perpendicular to the occlusal plane is considered to be ideal (11,12). However, the procedure is limited by bone quality, anatomical structure, and clinical practice, possibly resulting in implant inclination from the ideal path of insertion (13). Walton et al. (13) found that 18 of 82 implants placed in the canine areas of the mandible tipped medially toward the midline.

Many clinical studies have reported high survival rates for tilted implants (14,15). However, tilted implants
interfere with denture construction by preventing a common path of insertion with individual attachments. They also transmit increased stress to the bone compared with vertically placed implants (16,17). The increased stress may cause bone resorption and microdamage (18,19). Bending movements that result from nonaxial overloading of dental implants may cause stress concentrations around the implants. When these stresses exceed the physiological supporting capacity of the cortical bone, marginal bone loss may occur in the form of craters, in which microorganisms can lodge and cause periimplantitis, leading to implant failure (20).

The effect of distal (21-23) and mesial (24,25) inclinations of two-implant-retained overdentures with Locator attachments have been investigated. However, data regarding peri-implant strain around two-inclined implant-retained overdentures remain scarce (17,26-28). In a finite element study, Hong et al. (26) found higher strains and less equal stress distribution in peri-implant bones for all inclined implants compared with those in parallel implant-retained overdentures with ball anchors. They also stated that distal angulation showed the highest mean increase in stress, whereas buccal inclination showed the lowest mean increase. Another photoelastic analysis (28) revealed higher stress concentration around the mesial and distal implant surfaces in implants that diverged from the midline compared with that around parallel implants. In a finite element analysis, Caetano et al. (28) found increased stress on the peri-implant bone in two implants that were inserted at 10° latero-lateral inclinations and connected to overdentures using bar-clip attachments. Elsyad et al. (17) recently evaluated the impact of distal implant inclination on peri-implant strains with mandibular overdentures with Locators attachments and found increased strains when the angle of the implant inclination increased compared with parallel implants.

Most studies evaluating the stress around the inclined implant-retained overdentures are concerned with distal inclination (17,26-28). However, the effect of mesial implant inclination on strain transmitted by Locator-retained overdentures has not been investigated. Hence, this study aimed to assess the effect of different degrees of mesial implant inclinations on strain around two-implant-retained overdentures using resilient Locator anchors.

**Materials and Methods**

**Experimental models and overdentures**

This study was conducted on four duplicate, completely edentulous mandibular acrylic models. Two 13 × 3.7-mm implants (TioLogic, Dentaurum, Ispringen, Germany) were inserted in the canine areas of each model. Artificial acrylic resin teeth were arranged on a wax trial denture base. The trial denture was flaked and packed with clear acrylic resin to obtain a guide template, which was used to mark the implant placement sites for each model (29).

Using a parallometer milling machine (TDS cutter, Turbdent system, Jabil Green, Taichung, Taiwan), two recesses were prepared in the marked sites in the canine areas (17). The models were classified into the following four groups on the basis of the degree of mesial implant inclination: 0°, 5°, 10°, and 20° (Fig. 1). Drill inclination was controlled by moving the table of the milling machine in a mesio-distal direction. The implants were inserted in the prepared recesses with platforms leveled at the crest of the acrylic ridge. The implants were fixed to the acrylic models using a resin cement to simulate osseointegration (30). For each model, an approximately 1.5-mm layer of silicone soft liner (GC Reline Extra soft, GC Corp., Tokyo, Japan) was used to simulate the alveolar mucosa (6,17,29,31,32).

Twenty duplicate experimental overdentures (five experimental overdentures/group) were constructed over the models. This sample size was selected on the basis of the power analysis performed in a previous study (17) to yield a power of 98% with a type I error of 0.05.

Each overdenture comprised a mandibular record block (wax denture base and occlusion rim). The Locator attachments (TioLogic, Dentaurum) comprised black processing inserts that were attached to Locator matrices, and the assembly was plugged on to Locator abutments. Sufficient relief spaces were provided on the fitting surface of the overdentures, which corresponded to the implants to accommodate the metal housings of the Locator attachments. The Locator matrices were attached to the fitting surface of the overdentures using autopolymerized acrylic resin (Fig. 2). The black processing inserts were replaced with pink nylon inserts (low retention, 1.365 g) for all inclinations (0°, 5°, 10°, and 20°); red-extended range inserts (low retention, 680 g; manufactured without internal frictional flange for highly angled implants) were used for 20°red.

**Strain gage fixation**

At least 5 mm of the silicone mucosal simulation was removed from the mesial, distal, buccal, and lingual areas around the implants to permit bonding of strain gages to the acrylic resin. The acrylic resin surfaces were flattened with a fissure bur, as recommended by the manufacturer. The surfaces were then smoothed using a fine grit sandpaper to obtain a surface texture suitable for strain gage bonding and to avoid incremental
apparent strain. Four linear strain gages (Type KFG-1-120-C1-11L1M2R; gage length, 1 mm; gage resistance, 119.6 ± 0.4 Ω; adaptable thermal expansion, 11.7 PPM/C; temperature coefficient of gage factor, +10118%/C; gage factor, 2.08 ± 1.0%) were bonded to the acrylic resin at the mesial (M), distal (D), buccal (B), and lingual (L) surfaces of each implant (17,31). A strain gage adhesive (Kyowa Electronic Instrument Co., LTD., Tokyo, Japan) was used to monitor the strain around the implants during load application (Fig. 3). The gages were oriented mesiodistally perpendicular and bucco-lingually parallel to the implant axes.

Acrylic dummies were constructed to control thermal changes that resulted from loading (17). Active and dummy gages were wired to a half-circuit Wheatstone bridge (four-way armored cable, AF4 × 1 × 28; AWG, Pirelli, Sao Paulo, Brazil). The other half of the bridge was internally located using in a digital strain meter (Cio-Exp-Bridge 16; Measurement Computing, Middleboro, MA, USA).

A static load, ranging from 10 to 60 N, was applied 5 times (in 10 N steps) to the occlusal surface of the record block using a loading device to calibrate the gages. The calibration process aimed to verify the linear association between the applied load and resultant strain and assess the repeatability of the measurements (6,17,29,31,32).

**Strain measurement**

A universal testing machine (Model-2006, Instron Corp, Canton, MA, USA) was used to deliver vertical static loads of 100 N (33) bilaterally (to simulate clenching in centric occlusion) and unilaterally (to simulate chewing on preferred side). This amount of force represents a moderate level of biting force on implant-retained overdentures (33,34). The load was applied in a compression mode at a constant rate (cross head speed) of 0.5 mm/min (5).

For bilateral loading (Fig. 4), a metal bar was placed on the occlusal plane of the occlusion rim between the right and left denture bases in the region of the mesial cusp of the first molar. The bar was then cemented in position using epoxy resin. The forces were delivered to the center of the metal bar using the loading pin of the loading device (6,17,29,31,32). For unilateral loading
(Fig. 5), strains were measured at the M, D, B, and L peri-implant sites on the loading (right) and nonloading (left) sides. The point of load application was selected at the central occlusal fossa of the first molar and notched with a diamond bur. This was performed to accommodate the loading pin at the same location (for reproducibility) and to prevent the slipping of the pin during loading (6,17,29,31,32).

Electric signals from the four strain gages were collected at a rate of 2 Hz (two readings/s) and were amplified, transmitted, and recorded using a software package (KYOWA PCD, Kyowa Electronic Instruments Co.). All experiments were repeated 5 times for each denture, and the mean recorded microstrain was subjected to statistical analysis.

Statistical analysis
Mixed ANOVA was used to compare strains between groups (0°, 5°, 10°, 20°, and 20°red), sites of strain gages (M, D, B, and L), and load applications (bilateral and unilateral), followed by Bonferroni post hoc test. A $P$ value of <0.05 was considered to be significant.

Results
Negative values indicated compressive strains, and positive values indicated tensile strains. For all implant inclinations, most strain gages recorded compressive strains at the distal surfaces and tensile strains at the mesial surfaces. There was a significant difference in strains between the implant inclinations (Table 1). The 20° recorded the highest microstrain values, followed by 10° and 5°; both 20°red and 0° recorded the lowest values. A significant difference was also noted between the strain gage positions (Table 2). The distal site showed the highest strain, followed by the mesial and buccal sites, with the lingual site presenting with the lowest strain. Unilateral loading recorded significantly higher strains than bilateral loading (Table 3). The loading side showed significantly higher strains than the nonloading side (Table 4).

Comparisons of strains between implant inclinations and strain gage positions during bilateral loading are presented in Table 5. Except buccal strain gage, there was a significant difference in strains among implant inclinations for all strain gage positions ($P < 0.05$). The 20° inclination recorded the highest strain, whereas lowest strains were recorded with the 5° (for mesial and distal gages) and 0° (for buccal and lingual gages) inclinations. No significant differences between strain gage positions were noted for all inclinations, except 10° and 20°red, in which the distal sites presented with the highest strain, whereas the buccal/lingual sites showed the lowest strain.

Comparisons of strains between implant inclinations and strain gage positions on the loading side are presented in Table 6. There was a significant difference in strains among implant inclinations for all strain gage positions ($P < 0.05$). In the mesial and distal sites, the highest strain was recorded at 20° followed by 10°, and the lowest strain was recorded at 0°. In buccal and lingual sites, the highest strain was recorded at 5°, whereas 20°red presented with the lowest strain. With the exception of 5°, distal gages recorded the highest strain, whereas the lowest strains were recorded on the mesial (0° and 5°), lingual (10° and 20°), and buccal (20°red) sites.

Comparisons of strains between implant inclinations and strain gage positions on the nonloading side are
There was a significant difference in strains among implant inclinations for all the strain gage positions ($P < 0.05$). In the mesial and distal sites, $20^\circ$ showed the highest strain, followed by $20^\circ$ red, $0^\circ$, and $5^\circ$; the lowest strain was noted at $10^\circ$. In the buccal and lingual sites, $0^\circ$ presented with the highest strain, whereas $10^\circ$ (lingual) and $20^\circ$ (buccal) had the lowest strain values. The highest strain values were noted at $0^\circ$ on the lingual sites; at $5^\circ$, $10^\circ$, and $20^\circ$ red on the buccal sites; and at $20^\circ$ on the distal site.

**Discussion**

Most gages (particularly the distal gages) recorded compressive strains for all degrees of implant inclina-
tions. Similarly, Watanabe et al. (35) noted compressive stresses on the side of the inclination and tensile stresses on the other side. In contrast, Elsyad et al. (17) found tensile strains on the distal gages when implants were distally inclined. These conflicting results could be attributed to the difference in the direction of the implant inclination between the two studies. The movement of the mesially inclined implants in a distal direction compresses the acrylic resin on the distal implant surface, whereas the mesial surface of the implants are subjected to tensile strains (27).

The study results demonstrated increased strain values around implants as the angulation increased in all cases, except in those where red male inserts were used. Similar observations were previously reported (16,17,26,35,36), wherein the tilting of single implants was associated with increased peri-implant bone stresses compared with stresses observed around vertical implants. This increase in strain may be attributed to the double frictional flanges of the male nylon inserts, which provide limited hinge movement (8°) during posterior load application on the denture saddles (37,38). Moreover, Locator abutments feature internal and external undercuts, which resist removal of the resilient patrix insert. If the matrix abutment is not identically aligned to the removal path of the patrix insert, large undercuts are created on the mesial and distal sides of the angled implants (22). These undercuts increase in size as the degree of implant angulation increases. Clinically, an increase in implant inclination may increase micromotions around the implant with Locator attachments during posterior occlusal loading because the patrices needed to be removed in unison. These undercuts limit the rotational and hinge movements of the denture, and therefore, may transmit large strains to the implants, possibly resulting in increased bone resorption owing to the acceleration of bone microdamage (18,19).

The lowest strain observed with 20°red in this study is consistent with that previously reported (17) and may have been occurred because of the absence of internal frictional flange in the red inserts, which reduces friction and minimizes undercuts created by inclined implants. The pink inserts have internal and external flanges, which restrict denture rotation, thus transferring more strain to the implants during posterior loading than the red inserts (37). Therefore, in clinical situations when implants pose greater mesial inclination, red inserts are recommended to retain the overdentures on the implants. This permits freedom of overdenture rotation and minimizes implant micromotion, which can affect the peri-implant marginal bone.

On the nonloading side, the parallel or slightly inclined implants recorded the highest strain values, whereas the severely inclined implants (10° and 20°) recorded the lowest strain values. This may be attributed to overdenture rotation and rocking around the sagittal axis that passes through the implants on the loading side. Therefore, overdenture tends to intrude toward the mucosa on the loading side and dislodges from the Locator abutment on nonloading side. The direction of dislodgement is toward the mid line (in a mesial direction), which is the same as that of implant inclination on the nonloading side. Attachment disconnection rapidly occurs as the angle of the mesially inclined implant increases on the nonloading side. In contrast, when the implant on the nonloading side is placed vertically or with a slight mesial inclination, the Locator abutment hinders the denture rotation, thereby increasing the strain. In the clinical setting, patients with mesially inclined implants are recommended to remove the denture by applying a rotational dislodging force unilaterally in a mesial direction to dislodge the dentures without transmitting increased strains to the peri-implant regions.

On the loading side, increased strain at the distal strain gages may occur because of the rotation of the overdenture on the Locator attachment. Mesially inclined implants tend to move in a direction opposite to the inclination (in a distal direction). This movement results from the cantilever action of denture saddles caused by mucosal resiliency when an occlusal load is applied on the molar areas (31). The acrylic resin at the distal surface of the mesially inclined implants hinders the movement of the implants distally, resulting in increased strain at the distal surface and decreased stress on the mesial and lingual sites, which occurs owing to the resistance of the acrylic resin to compression (27). Increased strain at the distal side of the implant loading side has been reported in several in vitro studies using parallel (30,37,39) and inclined (40) implants. Furthermore, the increased strain observed on the lingual surface of the vertically oriented implant at the nonloading side in this study is consistent with another investigation (41), in which the authors reported increased lingual stresses near the implant neck. The upper edges of the cortical bone demonstrated a tendency to be displaced inward within the horizontal plane. The buccal and distal gages presented with the highest strain values at the nonloading side in the inclined implants. However, this may be because of the incomplete disengagement of the Locator attachments on the nonloading side when the denture rotates on the Locator abutments at the loading side. This incomplete separation occurred because of the presence of the double
frictional flange. Therefore, from a clinical point of view, balancing the occlusion when inclined implants are used to retain overdentures with Locator attachments may be advantageous to distribute the pressure on the working and balancing sides and to avoid the concentration of peri-implant strain on one side, which may augment bone remodeling and resorption (42).

Laboratory studies are preferred to clinical studies for evaluating stresses introduced in the bone around implants. In a clinical situation, it would not be possible to control factors such as bone density, implant angulations, direction and amplitude of forces, superstructure fit, and resilience of the soft tissue on the ridge (43). However, the major limitation of in vitro biomechanical stress analysis is the necessity to drive certain assumptions or to use materials that frequently do not simulate the complex nature of living tissues (44). Acrylic resin was used to simulate mandibular bone in several studies (6,17,20,29-34,37,39,44) because of similarities in the modulus of elasticity between the compact bone and acrylic resin. However, the acrylic resin does not duplicate the exact physical and mechanical characteristics of mandibular bone. Moreover, the simulated loads were vertically applied; the absence of nonaxial load application is another study limitation.

Finally, the effect of mesial implant inclination on peri-implant stresses in two-implant-retained mandibular overdentures is only a part of the overall stress analysis. Future studies evaluating the impact of buccal and lingual implant angulation on peri-implant stresses around implant-retained overdentures are warranted. In addition, long-term clinical research is required to determine the influence of observed stress levels on peri-implant bone tissues, as well as the potential complications and maintenance of two-implant-retained mandibular overdentures with mesial implant angulation.

Conflict of interest
None declared.

References


