EGYPTIAN
DENTAL JOURNAL
www.eda-egypt.org

Vol. 68, 2679:2690, July, 2022

Print ISSN 0070-9484 • Online ISSN 2090-2360

Fixed Prosthodontics and Dental Materials

Submit Date : 26-04-2022 • Accept Date : 26-05-2022 • Available online: 30-06-2022 • DOI : 10.21608/edj.2022.134875.2084

EFFECT OF DIFFERENT IMPLANT NUMBERS AND LOCATIONS ON STRAINS AROUND IMPLANTS RETAINING MANDIBULAR OVERDENTURES WITH LOCATOR ATTACHMENTS. AN INVITRO STRAIN GAUGE ANALYSIS

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ABSTRACT

Aim: This in vitro study was performed to evaluate the effect of different implant numbers and locations on strains around implants retaining mandibular overdentures with locator attachments.

Materials and methods: Five implants were inserted in the interforaminal area of mandibular edentulous acrylic model in the following locations; 1) one in midline areas, 2 in canine areas and 2 in premolar areas. Locator attachments were used to connect mandibular experimental overdentures (n=5) to the implants. Two linear strain gauges were bonded at buccal and lingual surface of each implant. According to the implant number and location of the implants, the strain was measured (during unilateral and bilateral loading) using the following implant overdenture designs: Group 1: strains were measured around mid-line implant only, while the other locator attachments were disconnected. Group 2: strains were measured around the 2 canine implants only. Group 3: strains were measured around the 2 premolar implants only, Group 4: strains were measured around the midline and the 2 canine implants only, Group 5: strains were measured around the midline and the 2 premolar implants only.

Results: For midline implants during bilateral and unilateral loading, the highest strains were noted with group 1 and group 5, and the lowest strain was noted with group 4. For distal implants during bilateral loading, the highest to the lowest were group 3> group 2> group 4> group 5. For distal implants on the loading and non-loading sides during unilateral loading, the highest to the lowest were group 3> group 2> group 5> group 4. For group, 4 and 5, midline implants recorded the highest strain, then distal implants on the loading sides, and the lowest strains were observed on the distal implants of the non-loading sides.

Conclusion: within the limitations of this in vitro study, three implants used to retain mandibular overdentures with locator attachments were associated with reduced peri-implant strains than one or 2-implants regardless placement of posterior implants in canine or premolar areas. However, the midline implants is at increased risk of implant overloading than distal implants. This risk decreased when distal implants are positioned in canine areas.

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INTRODUCTION

Edentulous patients with resorbed mandibular ridges often experience problems with their complete dentures[1]. The stabilization of the lower denture with few inter-foraminal implants has provided reliable and predictable treatment outcomes due to the improvement of retention and stability of the dentures[2]. It has been reported in 2 consensuses that mandibular overdentures attached to two- implants are considered the minimum standard of care for the edentulous patient due to its relative simplicity, minimal invasiveness, and economy[2,3]. Another alternative treatment is the insertion of a single implant in the mandibular symphyseal region to retain an overdenture, especially in patients with bar socio-economic level[4]. Such treatment is simple, cost-effective, and has a minimal invasiveness [5] which might be beneficial in elderly (geriatric) patients with compromised medical conditions who had discomfort with their conventional denture[6]. This treatment gained popularity in the last two decades[6-12]. A third line of treatment is the placement of 3 implant in the interforaminal region to create an angular rather than a straight-line configuration [13]. This arrangement increases retention and reduces the number of planes of rotation. Moreover, the midline implant provides indirect retention for the prosthesis[14, 15]. This treatment is specially indicated with V-shaped ridge to avoid interference with tongue space[16] and has several advantages such as reduction of prosthesis movement, reduction of denture flexure, and distribution of stresses over a greater surface area. Furthermore, it gives increased implant support which allows connection of attachments at the distal aspects of posterior implants when indicated[17].

The overdentures can be attached to the implants with splinted attachments such as bars or unsplinted attachments such as locators (resilient studs), ball anchors, double crowns, and magnets[18] The unsplinted attachment provide easier hygiene[19], are cost-effective, have reduced prosthetic complications [15, 20], can be used with V-shaped arches without jeopardizing tongue space such as bars [21] and can be used when implants are positioned distally or in a diagonal arrangement. Compared to other unsplinted attachments, locators have reduced vertical height [22], increased retention provided by inner and outer frictional flanges [23], different degrees of retention and can be used with nonparallel implants [23]. Moreover, such attachment is resilient, self-aligning[15, 24] and can be used with limited inter arch space to avoid denture base deformation and fracture[25]

Biomechanical studies have suggested that the main cause of bone resorption is implant overload[26]. The load transmission to the implants and the surrounding bone depends on the type of loading, the type of prosthesis, quantity and quality of the surrounding bone, the type of attachment, and the implants number and distribution[27]. Strain gauge analysis is a commonly used method in dentistry for biomechanical evaluation of stress distribution in vivo[28, 29] as well as in vitro[30-32].

Implant position and number can be controlled by the surgeon to provide successful osseointegration[1]. For the edentulous mandible, placement of implants is usually performed in the interforaminal area, particularly in the region of canine and first premolar teeth due to the presence of good bone volume/density, and absence of vital structures[33]. This location also permits easy access for the patient and clinician[34]. In this area, three options for implant placement are possible: lateral incisor, canine, and premolar[1]. Reviewing the literature, there is no agreement about the optimum implant number and location that should be used for overdentures. Hong et al. suggested that when the amount of alveolar bone at the lateral incisor and canine positions is comparable, the lateral incisor areas could be chosen instead as it was associated with reduced peri-implant stresses[1]. On the other hand, Scherer et al.[35]demonstrated that implants inserted at the premolar position may be a more-viable position for an implant-retained overdenture therapy compared with implants inserted in the lateral incisor or canine positions. Moreover, Cordioli et al.[36]and Krennmair & Ulm [37]suggested the use of an overdenture with a single implant at the midline area with successful long-term clinical results. Accordingly, the aim of the present study was to evaluate, using strain gauge analysis, the effect of different implant numbers (one, two, and three) and locations (midline, canine, and premolar areas) on strains around implants retaining mandibular overdentures with locator attachments. The null hypothesis was that there will be no significant difference in peri-implant strains between the different numbers and locations of implants.

MATERIALS AND METHODS

Fabrication of the test model and experimental overdentures

This study was conducted on an acrylic model that was constructed from a duplicate of a stone cast representing normal edentulous mandibular ridge of adequate height and width has no undercuts. For standardization of strain gauge positions and loading conditions, the same model was used for all measurements[38]. The duplication was made using silicone impression to create a mold into which molten wax was poured to create a wax model. The model was flask, packed with heat-cured acrylic resin (Acrostone heat cure acrylic resin, Egypt) using long cycle using, finished and polished. A mandibular denture was constructed over the model to be used as a guided template for implant placement. The model was mounted to the table of a dental surveyor (Degussa AG, Frankfurt, Germany). The implant drills were attached to a straight handpiece that is mounted to the vertical arm of the surveyor. Using the template, five implant holes were drilled in the following locations: 1) one hole at midline, 2) 2 holes at right and left canine locations, and 3) 2 holes at right and left premolar locations. Five implants (3.7 mm in width, 11 mm in length, Dentaurum, Ispringen, Germany) were fixed in the holes using self-cure acrylic resin to simulate Osseointegration. The implants were oriented parallel to each other and leveled at the crest of the ridge. A thickness of 1.5mm soft liner material (Promedica, Neumünster, Germany) was applied on distal extension saddles of the model to simulate the soft tissue covering the ridge. Wax spacers were applied on the distal extensions and the model was flasked to create a mold into which the soft liner was packed after painting the appropriate adhesive. No attempt to apply the silicone soft liner material between the implants as this material will need to be removed later for the application of strain gauges. Locator abutments (gingival height 2.5mm) were threaded into the implants at 25Ncm torque (fig 1). Locator housings with processing the caps were snapped on the abutments.

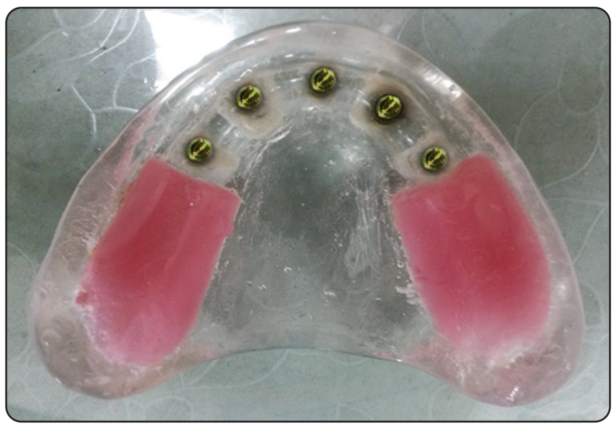

Fig. (1) Locator abutments screwed to the implants on the model

Five duplicate experimental overdentures were constructed over the model. Each overdenture consisted of an acrylic denture base with an occlusion rim (without denture teeth). The occlusal plane of the experimental overdentures was leveled at 2/3 the retromolar pad. The acrylic model was duplicated into a stone model on which an experimental overdenture was waxed and flasked. The five acrylic experimental overdentures were constructed using the same mold. For each experimental overdenture, five metal housings with medium retention nylon inserts (Pink; 1.365 g) were snapped over the locator abutments and picked up to the fitting surface of the overdenture using self-cure acrylic resin (fig 2). Before picking up procedures, Locator white blocking rings were placed over each abutment to prevent contact of excess acrylic resin with the abutments. After pick-up procedures, the excess acrylic resin that contact the abutments was removed to avoid transmission of increased load to the abutments during posterior occlusal loading.

Fig. (2) Locator metal housings with pink nylon caps attached to the fitting surface of experimental overdentures

Strain gauge analysis

A) Bonding of strain gauges:

Two strain gauges (KFG-1-120-C1-11L1M2R. Length =1 mm, Resistance=119.6±0.4Ω, Kyowa, Tokyo, Japan) were attached at the buccal and lingual surfaces of each implant[38, 39]to measure the peri-implant strains during loading (fig3). The surface of the acrylic resin should be flattened by use of acrylic bur and roughened with a sandpaper disc. A strain gauge adhesive (CC-33 Cement) provided by the manufacturer was used to cement gauges to prepare surfaces parallel to the long axis of each implant. The wires of the strain gauges were fixed to the base of the model and labeled to identify the location of each gauge[38]. Dummy rectangular-shaped acrylic control specimens were constructed to control any thermal changes resulted from loading the model. Fee end of the 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. Japan) and a digital Strain meter which convert resistance change to a voltage output

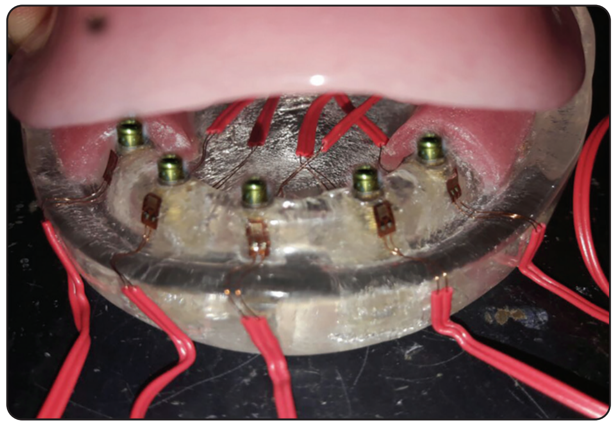

Fig. (3) Strain gauge positions around each implant

B) Calibration of strain gauges:

Before performing the measurements, which is mandatory to ensure that strain gauge readings are reliable. Consequently, a calibration of the gauges should be made to ensure the repeatability of the measurement. This is achieved when a linear correlation exists between the applied load and the resultant strains. Therefore, an increased load from 10 to 100 Newton was applied and the resultant microstrains (microvolts, μV) were calculated. The relationship between the applied load and the resultant microstrain values should be linear before performing the actual measurements[40, 41]

C) Measurements of strains:

According to the implant number and location of the implants, the strain was measured to the following implant overdenture designs:

1. Group 1: peri-implant strains were measured around mid-line implant only (fig4a), while the other locator attachments were unscrewed and the implants covered with the cover screws.

2. Group 2: peri-implant strains were measured around the 2 canine implants only (fig4b), while the midline and the premolar locator abutments were unscrewed

3. Group 3: peri-implant strains were measured around the 2 premolar implants only (fig4c), while the midline and the canine locator abutments were unscrewed

4. Group 4: peri-implant strains were measured around the midline and the 2 canine implants only (fig4d), while the premolar locator abutments were unscrewed

5. Group 5: peri-implant strains were measured around the midline and the 2 premolar implants only (fig4e), while the canine locator abutments were unscrewed

A universal loading device (LLOYD, Hampshire, United Kingdom) was used to apply a 100 Newton[42] vertical load bilaterally and unilaterally at a crosshead speed of 0.5mm\min[43]. Bilateral load application was performed by application of load (using the loading pin) on the center of a metal bar that connects the right and left denture bases at the first molar region (fig 5a). Unilateral load application was performed by application of load on the first molar area on the right side of the overdenture (the loading side), while the left side was considered the non-loaded side (fig 5b). The measurements were repeated 5 times (one for each experimental overdenture), allowing at least 5 minutes for heat dissipation[44], and the mean was used. The absolute magnitude of strain was summed for the buccal and lingual gauges of each implant and the mean was used in the statistical analysis.

Statistical analysis

The normal distribution of the data was confirmed by the Shapiro Wilk test. Consequently, the data were presented as mean± standard deviation. For both loading conditions (bilateral and unilateral loading), a two-way Analysis of Variance (ANOVA) was used to compare microstrains between different groups and implant positions (midline and distal implants which include canine and premolar implants) followed by Bonferroni post hoc test for pair-wise comparisons. $P < .05$ at a confidence interval 95% was considered to be the level of significance. The SPSS statistical package for social science version 22 (SPSS Inc., Chicago, IL, USA) was used for data analysis.

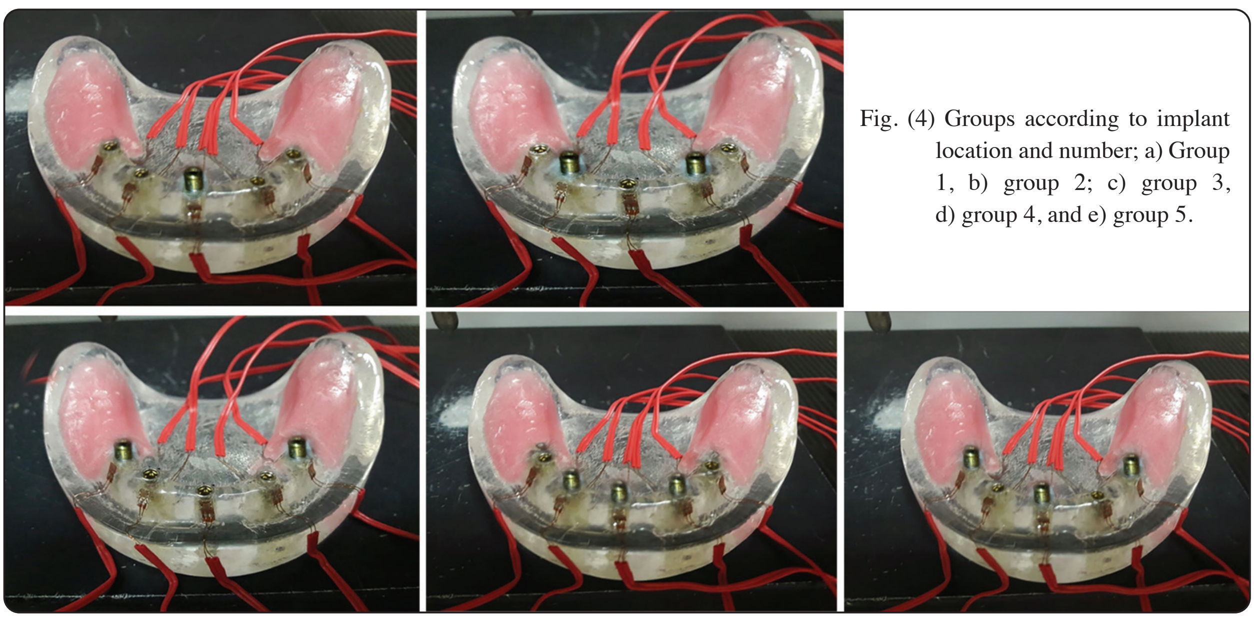

Fig. (4) Groups according to implant location and number; a) Group 1, b) group 2; c) group 3, d) group 4, and e) group 5.

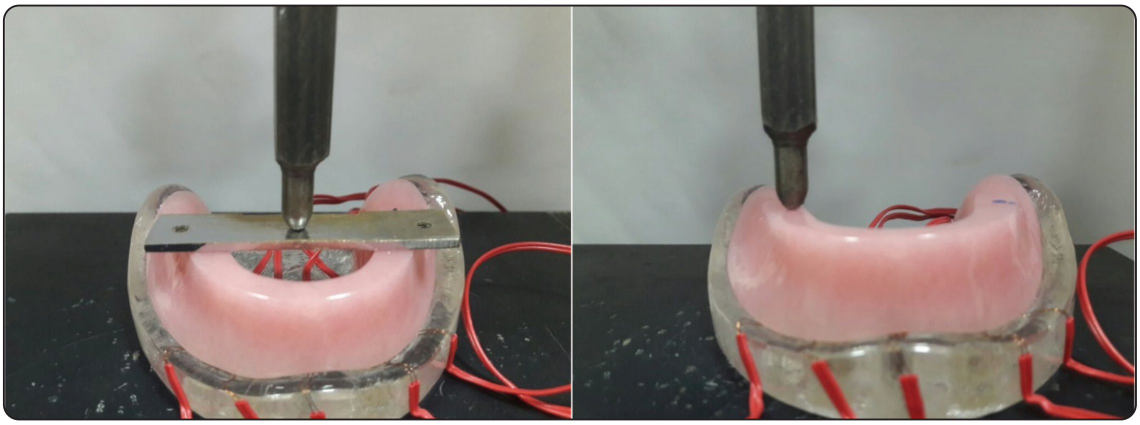

Fig. (5) Load application; a) bilateral loading, b) unilateral loading

RESULTS

During bilateral loading

During bilateral loading, the recorded microstrains for right and left canine implants were averaged and the mean was used for statistical comparisons. Similarly, the strains for right and left premolar implants were averaged and the mean was used. Comparison of microstrain values between groups (group 1 to 5) and implant locations (midline implants and distal implants) during unilateral loading is demonstrated in table 1. Multiple comparisons of strains between each two groups and each of two implant location using the Bonferroni correction is presented in the same table. For midline implants, the highest strains were noted with group 1, followed by group 5 (without significant difference in between), and the lowest strain was noted with group 4. For distal implants, the highest strain was noted with group 3, followed by group 2, then group 4, and the lowest strain was noted with group 5. There was no significant difference in strain between group 2, group 4, and group 5. For group, 4 and 5 midline implants recorded significant higher strains than distal implants.

TABLE (1) Comparison of microstrain values between groups and implant locations during bilateral loading

	Mid line implants		**Distal implants**		**t-test (p value)**
	X	SD	X	SD	
Group 1	255.10a	45.5			-
Group 2	-	-	52.40a	12.54	-
Group 3	-	-	110.30b	29.12	-
Group 4	123.00b	35.80	25.60a	6.80	<.001*
Group 5	220.00a	57.32	21.50a	4.26	<.001*
2-way **ANOVA (p value)**	<.001*		<.001*		

X: mean, SD: standard deviation. Different letters in the same column (vertically) demonstrated a significant difference between groups. * p is significant at 5% level.

During unilateral loading

During unilateral loading, canine and premolar implants at the right side are considered the distal implants at the loading side. On the other hand, the canine and premolar implants on the left side are considered the distal implants at the non-loading side. For statistical comparisons between groups, the same mean microstrain of midline implants was used on loading and non-loading sides. Comparison of microstrain values between groups and implant locations (on loading and non-loading sides) during unilateral loading is demonstrated in table 2. Multiple comparisons of strains between each two groups and each of two implant location using the Bonferroni correction is presented in the same table.

For midline implants, the highest strains were noted with group 1, followed by group 5 (without significant difference in between), and the lowest strain was noted with group 4. For distal implants on the loading side and on the non-loading sides, the highest strain was noted with group 3, followed by group 2, then group 5, and the lowest strain was noted with group 4. For distal implants on the loading side, there was a significant difference between group 2 and group 3. However, no significant difference in strain between group 4, and group 5 was noted. For distal implants on the non-loading side, no significant difference in strain between group2, group 4, and group 5 was noted.

For group, 2 and 3, distal implants on loading side recorded significant higher strains than distal implants on the non-loading side. For group, 4 and 5, midline implants recorded the highest strain, followed by distal implants on the loading sides, and the lowest strains were observed on the distal implants of the non-loading sides.

TABLE (2) Comparison of microstrain values between groups and implant locations during unilateral loading

	Mid-line implants (loading /non loading sides)		**Distal implants loading side**		**Distal implants non-loading side**		**2-way ANOVA (p value)**
	X	SD	X	SD	X	SD	
Group 1	285.10a	66.5	-	-	-	-	-
Group 2	-	-	98.30a	22.58	69.22a	19.78	.026*
Group 3	-	-	160.50b	49.25	116.50b	28.28	.012*
Group 4	190.36b,A	44.87	75.36c,B	17.70	55.47a,C	13.12	<.001*
Group 5	280.84a,A	66.36	84.95c,B	23.21	61.53a,C	20.23	<.001*
2-way **ANOVA (p value)**	.003*		.002*		.013*		

X: mean, SD: standard deviation. Different lower-case letters in the same column (vertically) demonstrated a significant difference between groups. Different upper-case letters in the same raw (horizontally) demonstrated a significant difference between implant locations on loading and non-loading sides. * p is significant at 5% level.

DISCUSSION

In this study, the strain gauges were attached near the crest of the ridge as it has been demonstrated that peri-implants stresses resulted from occlusal load usually concentrated in the crestal region of the bone around the neck of the implant rather than the entire surface of the implant[45]. The occlusal loading was delivered to the first molar area as this area was reported to be associated with increased occlusal bite forces with increased contraction of masticatory muscles[46]. The amount of delivered forces of 100 Newton was chosen as it represents the normal forces of mastication for implant overdenture patients[42]. It should be noted that all recorded microstrains was different implant locations and the numbers were below 2500 μ strains, which was detected as a physiological tolerance threshold of bone that may induce bone resorption[47].

For midline implants during bilateral and unilateral loading, the highest strains were noted with group 1 and group 5, and the lowest strain was noted with group 4. Similarly, in a finite element analysis, Liu[48] noted, an increased strain in peri-implant bone with overdentures retained by one midline implant and locator attachments when load was applied vertically on the molar region. They found also increased peri-implants stresses when 3 implants were used (one in midline and 2 in first premolar location). However, the authors did not find increased peri-implants stresses when load was applied on the incisors. The increased implants stresses around midline implants could be attributed to nature of overdenture movement during loading. The implant overdenture tended to hinge and rotate around the anteriorly positioned implants (in the interforaminal area) when posterior loading is applied. The presence of internal and external frictional flanges of the male nylon inserts which limit this hinge movement (8◦)[49] during loading on the first molar area thus transmitting more stress to the implants[41,50]. Even when 3 implants were used in midline and the premolar locations, the midline implants still have increased risk of overloading. This may be due to the vertical resiliency of locator attachments located in premolar positions may allow the posterior settling of the posterior portion of the overdenture during loading. Consequently, the overdenture hinge over the midline implant only, therefore, stresses around midline implants increased. In agreement with this explanation, Meijer et al[51] concluded that, when implants are widely distributed in the interforaminal area, increasing the number of implants were not associated with reduced periimplant strain. Another explanation for increased stresses when implants are inserted in midline and the premolars (group 5), may be explained by the increase in the supporting effect of the implants. With increased implant numbers, more of the chewing force was shared by the implants while less was borne by the mucosa, resulting in the increased stresses in the bone around the implants. Furthermore, in group 5, there is an angular relationship between the implants instead of a straight-line relationship (that is present in group 4). This counteracts the free overdenture rotation during posterior occlusal loading resulted in an increased strains around mid-line. This may explain the reduced peri-implants stresses around midline in group 4 is implants are located nearly in a straight-line which enhance overdenture rotation without implant overloading. These findings are in contrast to clinicians believes that with an increase in implant number, the maximum strain value in peri-implant bone would decrease and the strain in the bone would be more widely distributed[48]. The increased stresses around midline implants retaining overdentures (group 1) were in line with several studies which reported high failure rates for single-implant retained mandibular overdentures using an immediate loading protocol[52, 53]. On the other hand, Maeda et al. found that single-implant overdentures had biomechanical properties similar to two-implant overdentures in terms of lateral forces to the abutment and denture base movements under functional molar loads when bar and the magnetic attachments were used.[54] This may be due to ball and magnetic attachments allow free overdenture rotation without limitation of hinge movements.

Also, for group, 4 and 5 midline implants recorded significant higher strains than distal implants during bilateral and unilateral loading. There has been some concern that with three-implant overdentures, the strain in the bone around the middle implant may be high, especially when functioning with the posterior teeth[48]. In contrast, Geckili et al. also found that the marginal bone loss around the central implants of threeimplant mandibular overdentures, when using ball or bar attachments, was lower than around the implants on the left and right sides[55]

For distal implants during bilateral and unilateral loading, the highest strain was noted with group 3, followed by group 2, and the lowest strain was noted with group 4 and group 5. The increased strain for distal implants in group 3 (2 premolar implants) and group 2 (2 canine implants) could be attributed to the location of fulcrum line which connected the 2 premolar implants (group 3), and 2 canine implants (group 2). Consequently, during overdenture rotation, frictional flanges of locator inserts counteract hinging movement, and a closed increased peri-implants stresses as stated previously. The increased peri-implants stress in group 3 compared to group 2 may be due to premolar implant is located near the source of load application (first molar). The increased stresses in group 2 and group 3 compared to group 4 and group 5 is in line to the results of several authors. Liu, et al. [48] in a 3D finite element analysis noted that peri-stresses with locator retained mandibular overdentures on 2 implants inserted in canine positions was higher than 3 implants inserted in mid line and premolar positions when vertical load was applied. Also, Bilhan, et al.[39] found that during bilateral loading, the highest stress values were obtained in the 2-implant with ball attachments compared to 4 implants inserted in lateral and premolar areas or mid line implants. They concluded that, the increase in number of implants could reduce forces emerging around the implants during function. However, it should be noted that strain around implants in group 2 and group 3 is reduced compared to group 1. This agreed with results of Topkaya & Solmaz [56]. Therefore, two-implant overdenture has been considered a first choice for the treatment of edentulous patients worldwide[3].

In this study during unilateral implant loading, distal implants on loading side recorded significant higher strains than distal implants on the non-loading side. This was in agreement with several invitro strain gauge analysis[41, 50, 57-60] and may be attributed to the location of the implants on the loading side near the site of load application.

The limitations of this study include 1) absence of nonaxial load application which may occurred during mastication as the direction of occlusal force may change the patterns of peri-implant stress, 2) absence of strain measurements at the mesial and distal peri-implant sites due to limited area for the application of strain gauges, 3) as in other in vitro studies, the obtained information from strain gauge analysis is usually descriptive only as properties of acrylic resin do not simulate the complex nature of living bone.

CONCLUSION

Within the limitations of this in vitro study, three implants used to retain mandibular overdentures with locator attachments were associated with reduced peri-implant strains than one or 2-implants regardless placement of posterior implants in canine or premolar areas. However, the midline implants is at increased risk of implant overloading than distal implants. This risk decreased when distal implants are positioned in canine areas.

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