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Original article

Effects of different numbers of mini-dental implants on alveolar ridge strain distribution under mandibular implant-retained overdentures

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ABSTRACT

Purpose: To investigate the strains around mini-dental implants (MDIs) and retromolar edentulous areas when using different numbers of MDIs in order to retain mandibular overdentures.
Materials and methods: Four different prosthetic situations were fabricated on an edentulous mandibular model including a complete denture (CD), and three overdentures, retained by four, three or two MDIs in the interforaminal region with retentive attachments. A static load of 200 N was applied on the posterior teeth of the dentures under bilateral or unilateral loading conditions. The strains at the mesial and distal of the MDIs and the retromolar edentulous ridges were measured using twelve strain gauges. Comparisons of the mean microstrains among all strain gauges in all situations were analyzed.
Results: The strain distribution determined during bilateral loading experienced a symmetrical distribution; while during unilateral loading, the recorded strains tended to change from compressive strains on the loaded side to tensile strains. Overall, the number of MDIs was found to be passively correlated to the generated compressive strain. The highest strains were recorded in the four MDIs followed by three, two MDIs retained overdenture and CD situations, respectively. The highest strain was found around the terminal MDI.
Conclusions: The use of a low number of MDIs tends to produce low strain values in the retromolar denture-bearing area and around the terminal MDIs during posterior loadings. However, when using a high number of MDIs, the overdenture tends to have more stability during function.

1. Introduction

In some patients whose alveolar ridge morphology does not allow regular-sized implant placement without additional bone augmentation procedures, the mini-dental implant (MDI) may be an alternative form of treatment. These implants have been used to assist in the retention of overdentures in patients with atrophic ridges [1–4]. MDIs were able to retain the mandibular overdentures and showed that they can improve the quality of life of the patient, the degree of satisfaction of the patient, and the chewing ability of the denture-wearing patient [1,3].

Nevertheless, there are some concerns for patients who use MDIs. For example, some findings from the in vitro studies and the finite element analyses (FEA) have illustrated that stress values affecting the crestal cortical bone are reciprocal to the dental implant diameter and MDIs are prone to create a high level of strain in the bone around the MDIs as a result of the small diameter of the implant [5–9].

Although there are still concerns with regard to the negative biomechanical behavior of MDIs, the use of MDIs to retain overdentures has been continuously increasing [4,10]. In the edentulous mandible, four MDIs at the interforaminal region have been used for immediate loading with overdentures [1,3,11,12], whereas some authors have described an alternative method of retaining mandibular overdentures with only two MDIs [10,13,14]. Nevertheless, there has been limited available information regarding the number of MDIs and the amount of load transmitted to the alveolar ridge in MDIs-retained mandibular overdentures.

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Fig. 1. MDI compartments. MDI body (a), retentive screw (b), MDI body with retentive screw (c) and MDI with Equator retentive attachment (d).

This study was conducted to extend the overall understanding of the MDI number with regard to strain distribution. The objectives of this study are to observe the changes and relationships of the strains around the MDIs and the retromolar edentulous areas when using different MDI numbers to retain the mandibular overdenture.

2. Materials and methods

2.1. Specimen preparation

In this study, five MDIs, 2.75 mm in diameter and 12 mm in length, (PW+, Nakhon Pathom, Thailand) were used (Fig. 1). This MDI system consisted of two parts: the body and the retentive screw. The retentive screw head is designed to perform as a patrix of the retentive component, which will be joined in the matrix of the retentive attachment (Equator, Rhein83, Bologna, Italy).

Subsequently, each of the MDIs was coated with one millimeter of thickness of self-curing acrylic resin (Vertex Regular Crystal Clear, Vertex Dental B.V., Zeist, the Netherlands). After that, uni-axial strain gauges (KFG – 1N- 120- C1- 11N50C2; Kyowa Electronic Instruments, Tokyo, Japan) were attached in a vertical direction of the mesial and distal sections of the MDIs using a Cyano-acrylate based adhesives (CC-33A strain gage cement, Kyowa Electronic Instruments, Tokyo, Japan) (Fig. 2). MDIs locations were marked and drilled in the midline, lateral incisor, and canine regions of a simulated self-curing acrylic resin edentulous mandible model (Vertex Regular Crystal Clear, Vertex Dental B.V., Zeist, the Netherlands). All MDIs with attached strain gauges were placed parallel to one another using a surveying device (AF350 surveying and mulling device, Koblach, Austria). The distance between the center of the midline MDI and the lateral incisor MDIs was 5 mm, the distance between the centers of the lateral incisor MDIS was 10 mm, and the distance between the centers of the lateral incisor and the canine MDIs was 10 mm (Fig. 3).

All of the MDIs were then embedded into the model with the same materials until the same shape of the model was achieved. After that, the other two uni-axial strain gauges were oriented and attached in a bucco-lingual direction at the retromolar edentulous ridge of the simulated model. Therefore, a total of twelve strain gauges were used in this study. Each strain gauge has been labeled with an abbreviation (Fig. 4).

After the MDIs and strain gauges had been completely installed, the gingival tissue was simulated by being relined on the simulated model with polyether impression material (Impregum, 3M ESPE, St. Paul, Minn, USA) involving a uniform 2-mm-thick layer in the anterior edentulous area, and a 4-mm-thick layer in the retromolar area [15].

2.2. Overdenture fabrication

In this study, we used one mandibular complete denture as an experimental specimen by simulating four situations as follows: CD, 2-MDI, 3-MDI, and 4-MDI retained mandibular overdenture (Fig. 3).

With regard to MDIs retained mandibular overdenture fabrication, the five retentive screws of MDIs were put into all MDIs with an insertion torque of 20 N at the same time. The overdenture pick-up method were fabricated using self-cure acrylic resin (Rebase II, Tokuyama Dental Co. Tokyo, Japan) following the manufacturer's instructions. When tested in each situation, the retentive screws of the MDIs were removed or added, depending on the experimental group. Additionally, the denture base was adjusted to the untouched non-associated MDIs before being tested.

2.3. Loading application and strain measurement

In this study, 200 Newton (N) axial static loading was applied to the experimental overdenture through the use of a Universal Testing Machine® (UTM, Instron 5566; Norwood, MA, USA) for 15 s with the crosshead speed being set at 0.05 mm per minute [16]. This load level was selected as being within the range of normal occlusal mastication for implant overdenture patients that had been previously identified in literature [17,18].

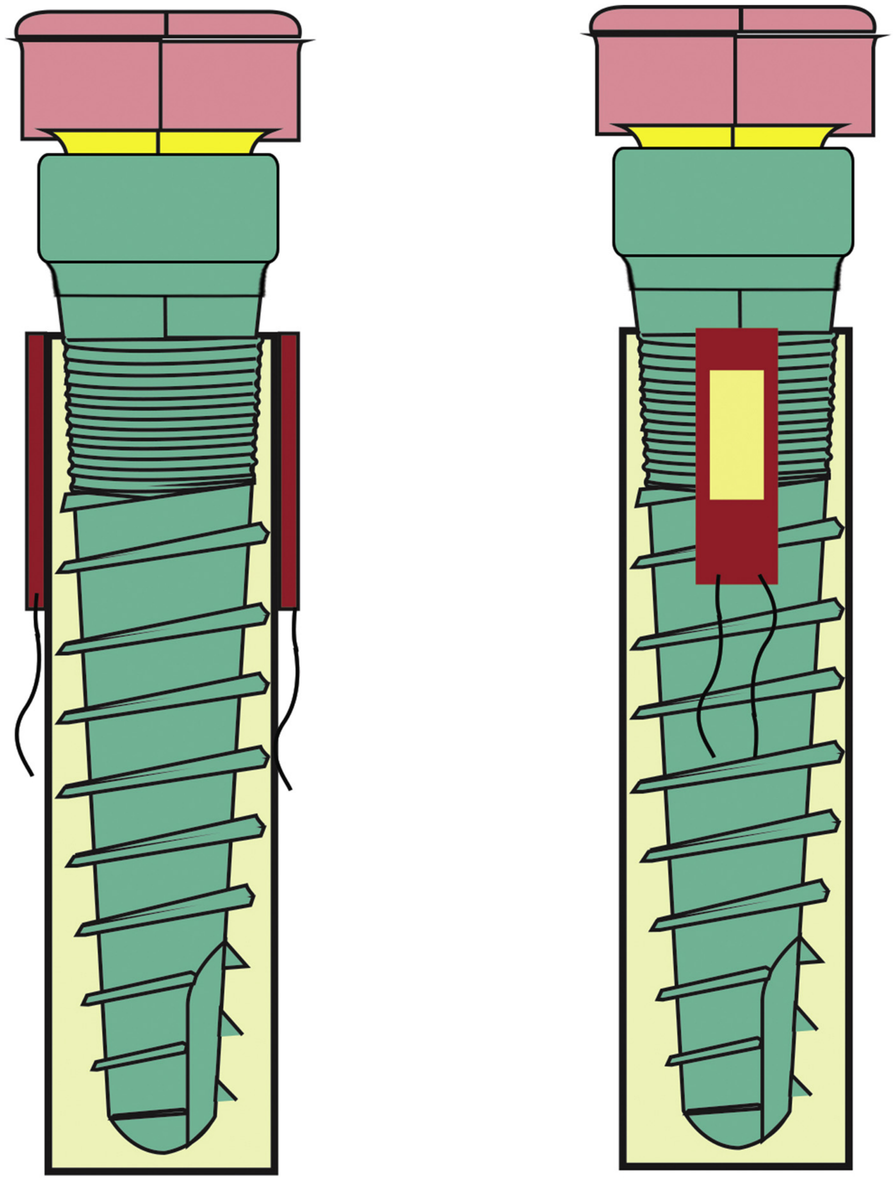

Fig. 2. Strain gauges installation. Strain gauges attached at mesial and distal side of the clear acrylic resin block (right), Proximal views of MDI with attached strain gauge (left).

The load application consisted of two conditions: bilateral loading and unilateral loading (Fig. 5). Regarding the process of bilateral loading, the load was delivered through a metal bar positioned between the right and left central occlusal fossa of the first molar to provide reproducibility. For the unilateral loading process, the load was delivered through a metal rod on the right side of the overdenture at the central fossa of the first molar. This procedure has been modified from Elsyad et al. [19]. Consequently, the right side was considered the loading side, whereas the left side was considered the non-loading side.

Ten measurements were applied under the same conditions in all situations and all conditions. Each period of loading allowed for at least five minutes of recovery time [18]. The strain values obtained from the uniaxial strain gauges were collected using a data acquisition system (NI PXIe-1023, National Instruments, Austin, TX, USA). The strain values acquired from the input module were analyzed by associated software (LabVIEW Signal Express 3.0; National Instruments, Austin, TX, USA).

2.4. Statistical analysis

The Shapiro–Wilk test was used to assess the normality of the microstrain. An independent sample *t* test was used to make comparisons between the bilateral and loading unilateral conditions. With regard to the group comparisons, the one-way ANOVA test was used followed by multiple comparison analysis using the post hoc test (Tukey). Spearman's rho test was used to evaluate the correlation between the mean microstrain values in each location and the MDI number. All data were analyzed using statistic analytical software (SPSS version 21.0, SPSS Inc., Chicago, IL, USA). A *P*- value of <0.05 was considered statistically significant.

3. Results

The data were parametric and normally distributed. The recorded mean microstrains and standard deviations recorded during the bilateral and unilateral loading conditions for all

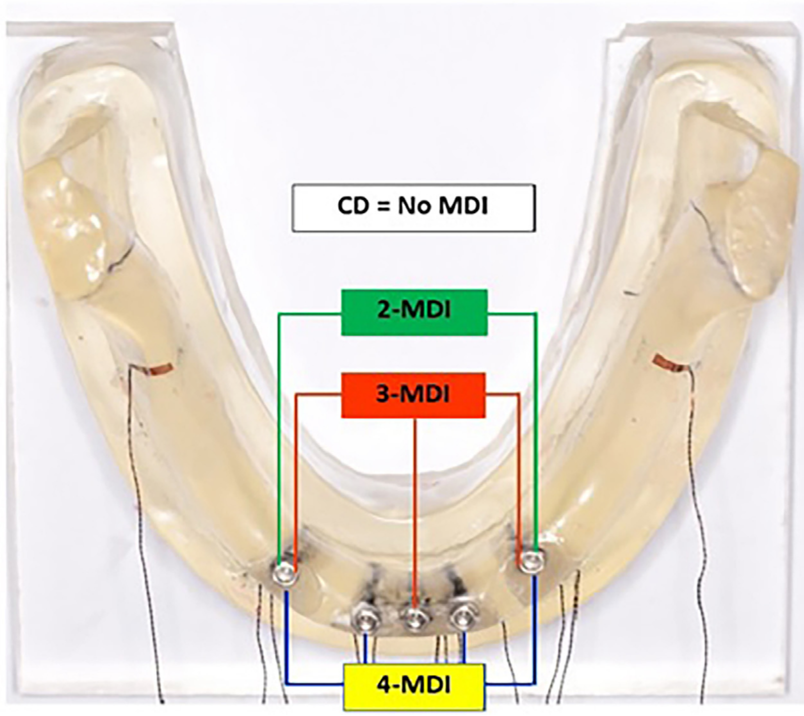

Fig. 3. Experimental situations and strain gauges in the simulated mandular model. CD = complete denture, 2-MDI = two-mini-dental implant retained overdenture, 3-MDI = three-mini-dental implant retained overdenture, 4-MDI = four-mini-dental implant retained overdenture.

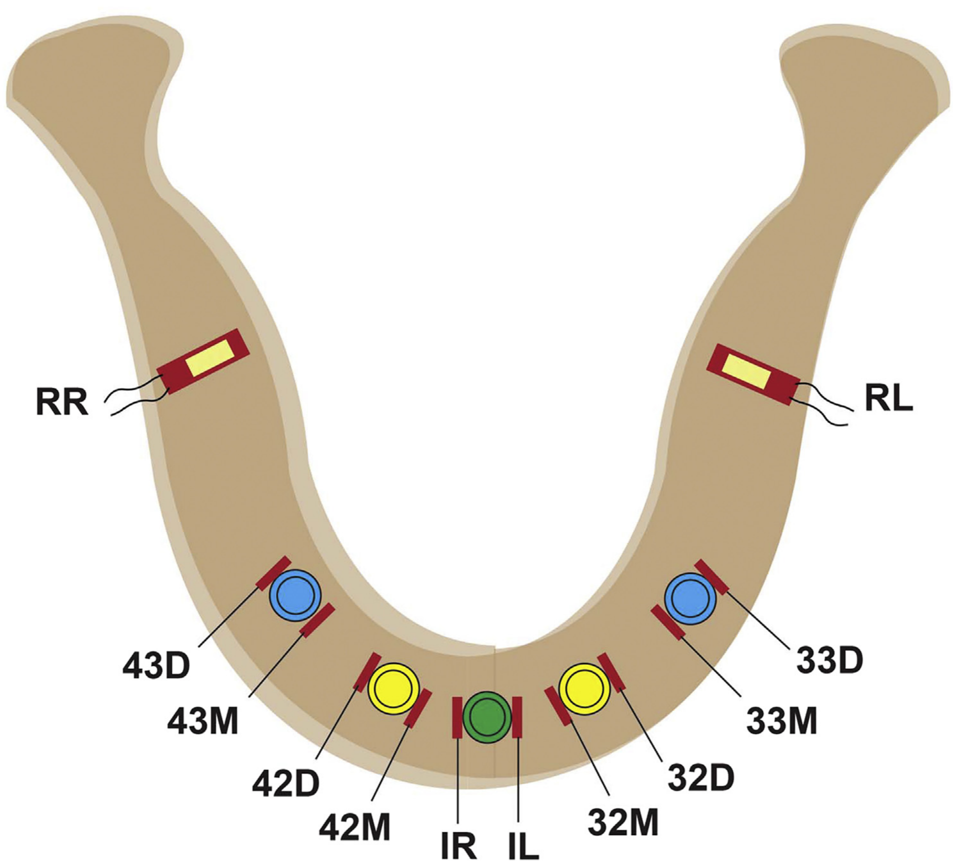

Fig. 4. Illustration of MDIs and strain gauge positions in the simulated mandibular model. Canine MDIs (blue), incisal MDIs (yellow), midline MDI(green), strain gauge positions; mesial and distal of left canine MDI (33M and 33D), mesial and distal of right canine MDI 43M and 43D), mesial and distal of left incisal MDI 42M and 42D), mesial and distal of right incisal MDI 32M and 32D), right and left midline MDI IR and IL), right and left retromolar denturebearing area RR and RL).

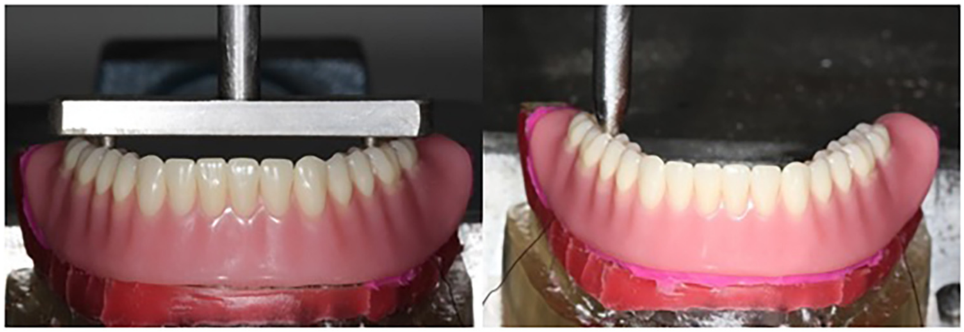

Fig. 5. Loading applications, bilateral (left) and unilateral loading conditions (right).

Table 1
Comparisons of mean microstrains between situations during bilateral loading.

Location	CD		2-MDI		3-MDI		4-MDI		One way ANOVA test	
	$\bar{x}$ (με)	±SD	$\bar{x}$ (με)	±SD	$\bar{x}$ (με)	±SD	$\bar{x}$ (με)	±SD	F value	*P* value
RR	−5.89	1.71	−34.16	4.52	−31.95	5.36	−49.50	4.41	128.11	0.00*
43D	−16.82	5.58	−41.33	2.28	−62.89	9.11	−66.56	6.50	91.17	0.00*
43M	−10.98	1.21	−17.42	2.51	−33.50	8.31	−44.01	4.18	67.2	0.00*
42D	−7.66	4.61	−18.43	3.46	−19.87	8.22	−51.56	5.82	74.43	0.00*
42M	−4.49	3.09	−10.12	5.6	−17.87	4.95	−57.30	6.12	155.27	0.00*
IR	−1.90	2.84	−0.57	8.22	−39.97	10.09	−56.68	6.79	98.42	0.00*

$\bar{x}$ = mean, με = microstrain, SD = standard deviation, + = tensile strain, − = compressive strain.
* One-way ANOVA, *P* value is considered significant at 0.005.

Table 2
Comparison of mean microstrains between situations during unilateral loading.

Location	CD		2-MDI		3-MDI		4-MDI		One way ANOVA test	
	$\bar{x}$ (με)	±SD	$\bar{x}$ (με)	±SD	$\bar{x}$ (με)	±SD	$\bar{x}$ (με)	±SD	F value	*P* value
RR	−6.86	6.31	−26.25^{B*}	4.94	−27.3	5.34	−46.09	9.85	37.88	0.00**
43D	−12.03	9.33	−80.03^{U*}	11.04	−109.52^{U*}	8.4	−223.68^{U*}	18.83	344.03	0.00**
43M	−10.78	8.14	−41.59^{U*}	4.46	−46.93^{U*}	5.53	−40.29	8.18	40.69	0.00**
42D	−2.67	5.68	−39.32^{U*}	8.77	−26.49^{U*}	6.94	−83.66^{U*}	6.64	160.49	0.00**
42M	−2.37	7.37	−37.96^{U*}	3.67	−36.39^{U*}	5.46	−102.17^{U*}	6.99	332.13	0.00**
IR	2.64	9.02	−40.81^{U*}	7.75	−44.64^{U*}	5.62	−66.86^{U*}	8.71	95.10	0.00**
IL	5.15^{U*}	10.63	−6.6^{B*}	4.70	−13.34 ^{B*}	6.84	−14.75^{B*}	6.16	10.51	0.00**
32M	3.36^{B*}	9.86	−10.43^{B*}	5.73	−12.16^{B*}	8.05	−24.25^{B*}	9.12	12.88	0.00**
32D	1.89^{B*}	10.19	−7.39^{B*}	6.16	−9.83^{B*}	7.12	−17.39^{B*}	7.29	7.20	0.00**
33M	−15.7^{U*}	7.59	8.86^{B*}	13.57	16.75^{B*}	8.62	38.49^{B*}	6.94	38.47	0.00**
33D	−14.09^{B*}	7.13	22.02^{B*}	4.77	16.09^{B*}	5.07	-22.02^{B*}	7.83	82.87	0.00**
RL	−4.67^{B*}	4.14	1.87^{B*}	3.74	9.26^{B*}	6.37	-4.8^{B*}	7.53	9.69	0.00**

$\bar{x}$ = mean, με = microstrain, SD = standard deviation, + = tensile strain, − = compressive strain, B = mean microstrain values during bilateral loading that were higher than those were during unilateral loading, U = mean microstrain values during unilateral loading that were higher than those were during bilateral loading.
* = *t* test, *P* value is considered significant at 0.05% level of significance.
** = One-way ANOVA, *P* value is considered significant at 0.05.

situations are presented in Tables 1 and 2, respectively. A compressive strain was represented by the minus symbol (−), whereas a tensile strain was represented by the plus symbol (+) in front of the strain values.

Mean microstrains recorded during the bilateral and unilateral loading applications in each situation were significantly different in almost all locations (*t*-test, $P < 0.05$) (Table 2). The MDI number was positively correlated to the compressive strain in almost all locations and the correlation coefficient values ranged from 0.051 to 0.944 (Spearman's rho test, $P < 0.05$) (Table 3).

In terms of the bilateral loading conditions (Table 1 and Fig. 6), all situations showed the compressive strain in all of the locations and the symmetrical distribution in nature. Therefore, only the mean microstrains on the right side were observed. The mean microstrains in all locations were significantly different in all situations (one-ANOVA, $P < 0.05$). In general, the highest compressive strains in all locations were recorded in the 4-MDI group followed by the 3-MDI, 2-MDI and CD situations, respectively.

With regard to the unilateral loading conditions (Table 2 and Figs. 7 and 8), mean microstrains in all locations were found to be significantly different in all situations (one-ANOVA, $P < 0.05$). With respect to the MDIs situations, the 4-MDI groups generally showed compressive strains except for 33M, which showed tensile strains. On the other hand, in the 2-MDI and 3-MDI groups, compressive strains on the loading side were observed, whereas on the non-loading side, the recorded strains tended to change from compressive strains to tensile strains. At the left canine MDI (33) in the 4-MDI group, the distal side showed compressive strains, while the mesial side showed tensile strains. However, at the same location in the 2-MDI and 3-MDI groups, the recorded strains were identified as tensile strains on both the mesial and

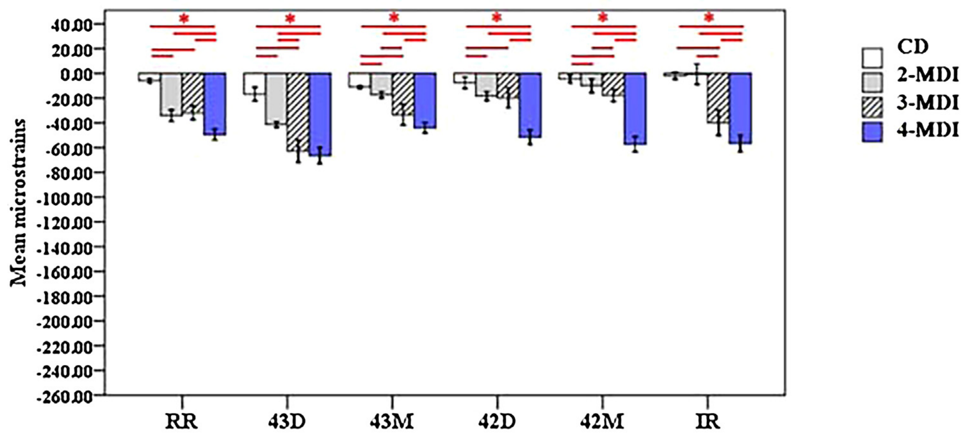

Fig. 6. Multiple comparisons between four different situations in right side strain gauge.
*P value is considered significant at 0.05.

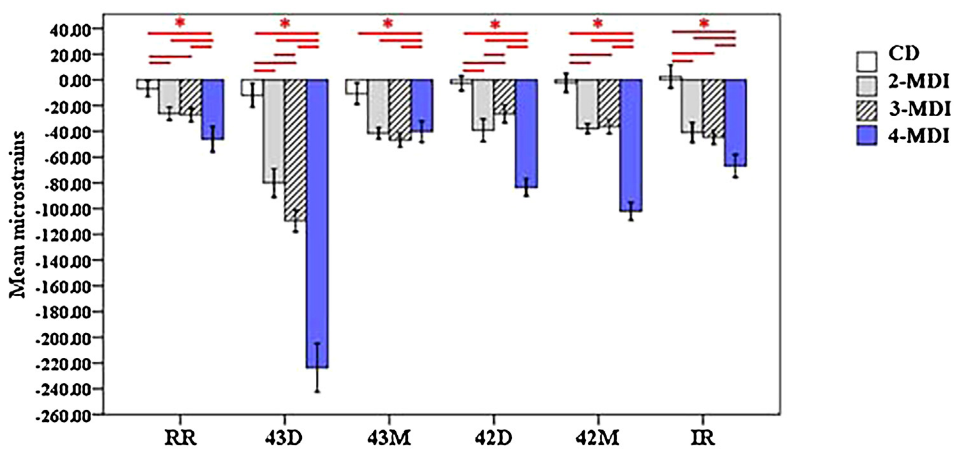

Fig. 7. Multiple comparisons between four different situations in loading side strain gauge locations during unilateral loading. *P value is considered significant at 0.05.

Table 3
Relationships between mean microstrains and implant number in each location during bilateral and loading conditions.

Location	Bilateral loading		Unilateral loading	
	Correlation Coefficient	P value Sig. (2-tailed)	Correlation Coefficient	P value Sig. (2-tailed)
RR	0.626	0.002*	0.742	0.000*
43D	0.790	0.000*	0.944	0.000*
43M	0.896	0.000*	−0.029	0.901
42D	0.722	0.000*	0.510	0.018*
42M	0.876	0.000*	0.684	0.001*
IR	0.905	0.000*	0.761	0.000*
IL	0.703	0.000*	0.520	0.016*
32M	0.896	0.000*	0.616	0.003*
32D	0.876	0.000*	0.549	0.010*
33M	0.925	0.000*	−0.761	0.000*
33D	0.886	0.000*	0.848	0.000*
RL	0.867	0.000*	0.327	0.147

*Spearman's rho test, P value is considered significant at 0.05.

distal sides. The highest compressive strain was found at 43D and the highest tensile strain was found at 33M in the 4-MDI group.

4. Discussion

A change in the number of MDIs to retain the mandibular overdenture has an effect on the strain distribution both around the dental implant and the retromolar edentulous ridges. An increase in the number of MDIs increased the strain proximal to the MDIs and on the retromolar edentulous area beneath the overdentures.

4.1. Effects of different loading applications on strain distribution

Generally, in this study, the characteristics of strain during bilateral loading were identified as compressive strain and symmetrical distribution, while the strain distribution patterns during unilateral loading were asymmetrical.

With regard to unilateral loading, the strains on the loading side tended to be identified as compressive strains, whereas the strains on the non-loading side tended to be tensile strains. This could be attributed to the realization that when bilateral forces are generated on the occlusal of the posterior teeth of the dentures, the denture base might then be rotated in a pitching pattern around the fulcrum. The force of pressure would then be transferred to the supporting structures, so the compressive strain was present around both the MDIs and in the retromolar edentulous area. When a unilateral force was applied, the anti-rotational moment would be created to prevent the displacement of the denture base from the gingiva in the same way as what occurred in the movement of a removable partial denture during single side chewing [20]. Therefore, the strain distributions between bilateral and unilateral loading were different.

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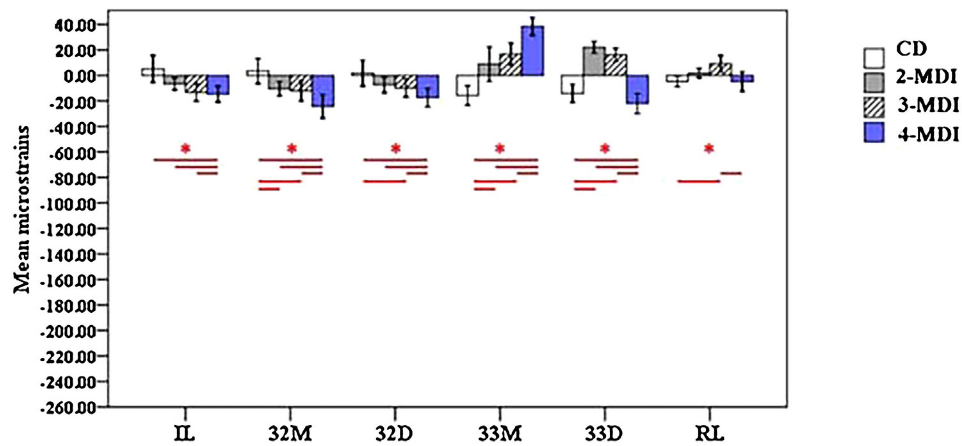

Fig. 8. Multiple comparisons between four different situations in non-loading side strain gauge locations during unilateral loading. *P value is considered significant at 0.05.

4.2. Differences of strain distribution in CD and MDI-retained overdentures

During bilateral loading, all of the mean microstrains found to be presented in the MDI situations were significantly higher than those in the CD group. This finding is in accordance with that of the study of Chen et al. in 2015, which found that the implants in the retained overdenture group showed a more significant increase in stress on retromolar mucosa than those in the CD group. This phenomenon is an effect of the implant at the anterior part of the mandible which would reduce the contact surface area between the denture and the oral mucosa; consequently, the recorded levels of strain in all IODs situations were higher than the recorded levels of strain in the CD group [21]. Additionally, Jacobs et al. observed a greater level of posterior residual ridge resorption among overdenture wearers as compared to CD wearers [22].

4.3. Effect of MDI number and strain distribution around MDI

In our study, the microstrain values around the MDIs increased as the MDI number increased. This finding was in accordance with Fatalla et al. [23] in that the maximum stress concentrations occurred in an overdenture that was supported by four MDIs, while minimum von Mises stress values were observed in an overdenture supported by three MDIs. However, the study of Fatalla et al. only focused on the level of stress at the attachment level and did not consider the level of stress around the MDIs. Moreover, that study did not simulate the two MDIs retained overdentures as we had in our study. Furthermore, Liu et al. explained that with increased implant numbers, more of the loading force was shared by the implant, resulting in increased peak strain values in the bone around the dental implants [24].

The highest strain values occurred at the terminal MDIs, especially at the distal of the canine MDI on the loading side during unilateral loading regardless of the loading conditions and the MDI situations. This may occur as a result of the concentration of the force. When a single posterior load is applied, the high stress value will be recorded at the nearest implant to the loading side [9,25].

In this study, during unilateral loading on the non-loading side in 2-MDI and 3-MDI situations, the recorded strains tended to change from compressive strains to tensile strains, while the 4-MDI group generally showed compressive strains at almost all locations. These findings may be a consequence of the fact that the 4-MDI group displayed the highest retentive forces, and as a result, the dentures were still found to be stable even though the high unilateral force was applied. Therefore, the compressive strains were generally recorded in the 4-MDI group. Scherer et al. found that in the system that provided a higher level of retention, the stability of the system would be further generated [26].

According to the results, the 2-MDI and 3-MDIs groups showed tensile strains in some observed locations; however, the tensile strains were recorded in only one location in the 4- MDI group. These tensile strains probably resulted from an effort to prevent the denture from being dislodged from the ridges. These findings can imply that the 2-MDI and 3-MDI retained overdentures tended to display more rotational movement than the 4-MDI retained overdentures. Recently, Liu et al., indicated that when a lower number of implants were used, the overdenture tends to rotate more around the fulcrum line [24]. An excessive amount of rotation of the denture around the attachments during masticatory function causes a loss of retention [27].

Furthermore, the one year survival rate of the 2-MDIs retained overdenture was lower than the survival rate of the 4-MDI retained overdenture [28]. Although, in our study, the 4-MDIs retained overdenture showed the highest levels of strain around the MDI under all loading conditions, a randomized clinical study [29] showed that there was no difference in marginal bone loss between 2-and 4-MDIs retained overdentures after a one-year follow-up period. This may imply that the generated strains in 4-MDIs are within the physiologic limits of the bone.

4.4. Effects of MDI number and strain distribution on retromolar edentulous area

Additionally, this current study found that the microstrain on the retromolar dentulous areas increased as the MDI number increased. This finding may in fact be the effect of an increased level of retention of the overdenture due to an increase in the flexible retentive attachments [30,31]. In fact, the level of retention and the freedom of rotation are closely related. A high level of retention of the IOD does not allow the denture base to rotate easily and is then consequently less likely to become displaced [21,32]. When the denture displacement is limited, all the forces will concentrate only at the denture contact area. Consequently, high recorded strain levels in the supporting areas increased [23,32,33]. These are the reasons why the microstrains both in and around the MDIs and retromolar edentulous areas in this study increased.

4.5. Relation of MDI number and the strain characteristics

In general, MDI numbers were positively correlated to the compressive strain at almost all locations. This finding implies that when the number of MDI increased, the denture tended to be pressed to the supporting structures or have more stability. Thus, the compressive strains were generated. Interestingly, the 33M location was negatively correlated with the compressive strain during unilateral loading. In other words, the strain in that location tended to be the tensile strain. This indicates that the terminal implant on the non-loading side plays a crucial role in resisting the bending forces. To prevent the pull-out force that may cause micro movements, which will bring about the MDI disintegration, patients should be advised to chew with both occlusal sides of the denture after immediate MDIs placement.

Finally, regarding the optimal number of MDIs that should be used for the high levels of stability and retention during the function of the high number of the MDIs used, 4-MDIs seem to be optimal. On the other hand, a reduction in the number of MDIs from four to two will reduce the amount of strain around the MDIs and in the retromolar edentulous area. In the event that the tissue support area is sufficient, the use of two MDIs used in retaining the mandibular overdentures is acceptable with regard to the strain distribution on the bone under the mandibular overdenture. However, a regular system of maintenance is crucial in preventing the occurrence of any subsequent complications after overdenture insertion due to a loss of retention.

To our knowledge, this study is the first study that has presented fundamental information about the effects of MDI number on strain distribution that was generated on the supporting areas beneath the overdenture. In this study, the axial strains in some locations around the MDI and on the retromolar area of the simulated mandible have been recorded. To further expand on the amount of information acquired on strain distribution, finite element analysis should be carried out to further support the results.

5. Conclusion

Within the limitations of this study, the following can be concluded: A reduction in the number of MDIs from four to two will reduce the amount of strain around the MDIs, as well as in the retromolar edentulous area. The 4-MDI retained mandibular overdenture tends to display the highest level of stability during function.

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