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Influence of marginal bone resorption on two mini implant-retained mandibular overdenture: An *in vitro* study

Ying Guo[1], Kentaro Kono[2], Yasunori Suzuki[3], Chikahiro Ohkubo[2], Jian-Yu Zeng[4,5]*, Jing Zhang[4]

[1]Department of Stomatology, Beijing Shijitan Hospital, Capital Medical University, Beijing, People's Republic of China
[2]Department of Removable Prosthodontics, Tsurumi University School of Dental Medicine, Yokohama, Japan
[3]Division of Oral and Maxillofacial Implantology, Tsurumi University School of Dental Medicine, Yokohama, Japan
[4]Center for Dental Implantology, School of Stomatology, Capital Medical University, Beijing, People's Republic of China
[5]Beijing Key Laboratory for Tooth Regeneration and Function Reconstruction of Oral Tissues, Beijing, People's Republic of China

ORCID
Ying Guo
https://orcid.org/0000-0001-6211-022X
Kentaro Kono
https://orcid.org/0000-0003-0591-4904
Yasunori Suzuki
https://orcid.org/0000-0002-4708-9327
Chikahiro Ohkubo
https://orcid.org/0000-0002-2062-8626
Jian-Yu Zeng
https://orcid.org/0000-0001-9130-3127
Jing Zhang
https://orcid.org/0000-0001-5314-2633

Corresponding author
Jian-Yu Zeng
The Beijing Key Laboratory for Tooth Regeneration and Function Reconstruction of Oral Tissues, Center for Dental Implantology, School of Stomatology, Capital Medical University, #4 Tiantan Xili, District Dongcheng, Beijing 100050, People's Republic of China
Tel +861352173-2662
E-mail zengjianyu@vip.sina.com

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PURPOSE. To investigate the biomechanical effect of marginal bone resorption (MBR) on the mandibular mini implant (MI)-retained overdenture (MI-OD) on the edentulous model. **MATERIALS AND METHODS.** The experimental mandibular edentulous model was modified from a commercial-model with 2 mm thick artificial soft tissue under denture base. Two MIs (Φ2.6 mm x 10 mm) were bilaterally placed between the lateral incisor and the canine area and attached with magnetic attachments. Three groups were set up as follows: 1) alveolar bone around the MI without MBR (normal group), 2) with MBR to 1/2 the length of the implant (resorption group), and 3) complete denture (CD) without MI (CD group). Strain around the MI, pressure near the first molar area, and displacement of denture were simultaneously measured, loading up to 50 N under bilateral/unilateral loading. Statistical analysis was performed using independent-samples t test and one-way ANOVA (α=.05). **RESULTS.** The strain around the MI with MBR was approximately 1.5 times higher than that without-MBR. The pressure in CD was higher than in MI-ODs (P<.05), while there was no statistical difference between the normal and resorption group (P>.05). Similarly, the CD demonstrated a greater displacement of the denture base than did the MI-ODs during bilateral and unilateral loadings (P<.05). **CONCLUSION.** The strain around the MI with MBR was approximately 1.5 times higher than that without MBR. The pressure on posterior alveolar ridge and denture displacement of MI-ODs significantly decreased compared to CDs, even when MBR occurs. Bilateral balanced occlusion was recommended for MI-ODs, especially when MBR occurred. [J Adv Prosthodont 2021;13:55-64]

KEYWORDS
Mini dental implant-retained overdenture (MI-OD); Marginal bone resorption (MBR); Magnetic attachment; Strain; Pressure distribution

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INTRODUCTION

As the aged population increases, the number of fully edentulous patients also tends to increase.[1] Although conventional standard-sized implant-retained overdentures (I-ODs) have proven to be clinically effective, I-OD rehabilitation has been selected for few edentulous patients.[2] Recently, mini dental implant (MI) overdentures (MI-ODs) have been applied as a convenient treatment option for edentulous patients in cases where standard-sized implants cannot be placed for economical and/or anatomical reasons.[3,4] MIs can be used in a variety of clinical situations and improve patients' satisfaction due to less bone grafting, quicker postoperative healing, less postoperative discomfort and less initial cost.[2,4-6] Compared to standardized implant, MI has a smaller implant surface area, which left it at greater risk of stress concentration.[7] However, for the alveolar ridge of same thickness, narrow implant may have sufficient buccal and lingual bone wall thickness, whereas the bone wall is thinner for wide diameter implant. In general, thicker bone wall reduced the strain magnitude in both bone layers and increased its resistance to stress.[8]

Two conventional implants retained mandibular overdentures have been considered the standard of care for complete edentulism, according to the McGill and York consensus.[9,10] As for MI, up to six implants have been used.[11] Recent clinical guidelines have advocated the use of four.[12] However, clinical studies described that the marginal bone resorption (MBR) and implant survival rate of two MIs retained mandibular overdentures is comparable to those of implants with a larger diameter in the short[6,13] and medium term (a mean observation period of 6 years).[14] Moreover, studies have shown that four MIs result in more postoperative pain than two MIs or two standard implants.[5] Therefore, two MIs as retainers for mandibular overdentures have been designed in the present study.

MBR surrounding implants has gained attention in recent years, congruent with the increase in the popularity of dental implant therapy. The longevity and success of dental implant relies on the integration of the implant in hard and soft tissues. Therefore, MBR was assumed to be a critical factor affecting the clinical outcome.[15] Multifactorial reasons were contributed to MBR, while the main theories have been the infection and overload.[16] The acceptable bone loss established in literature is 2 mm in first year after implant loading, followed by a maximum of 0.2 mm annually thereafter.[15,17] However, the pathological MBR can be more serious. For instance, in a 6-year retrospective study of severity of peri-implantitis, Saaby *et al*.[18] reported that patients with smoking habit suffered severe peri-implant bone loss of 5.3 mm (range: 2 - 11.5 mm), and nonsmokers showed a value of 3.5 mm (range: 2 - 7.5 mm). Despite the different degrees of MBR, those implants remained in the jaw and were still in function intraorally as "surviving implants".[19] However, with the effect of MBR, the biomechanical performance of the implants became more complicated and the risk of failure increased. In recent years, numerous studies[20-22] have been focused on the risk factors of MBR or the changes in bone level around implants, while scarce research concentrated on the biomechanical behavior of MI after MBR occurring, especially when it was utilized as a retainer of an overdenture.

Thus, the aim of this study was to analyze the biomechanical effect of MBR on the MI and MI-OD, including the strain surrounding the MI, the pressure distribution of the alveolar ridge, and the displacement of the denture base, retained by magnetic attachment under bilateral/unilateral loading, as compared to a complete denture (CD).

MATERIALS AND METHODS

Two experimental simulation models were prepared by modifying a commercial edentulous mandible model (Nissin Dental Products Inc., Kyoto, Japan). 2 mm parts from the surface of the original models were replaced by silicone impression material (Fit Checker, GC Co., Tokyo, Japan) to create a 2 mm thickness of artificial soft tissue under the denture base. The silicone impression material was mixed at a ratio of 6 bases to 1 catalyst to have the same amount of load displacement and elastic modulus. Two MIs (Φ2.6 mm × 10 mm, Platon Japan Co., Tokyo, Japan) were bilaterally placed in parallel at a distance of 22 mm from the center of the mandible bone on the as-

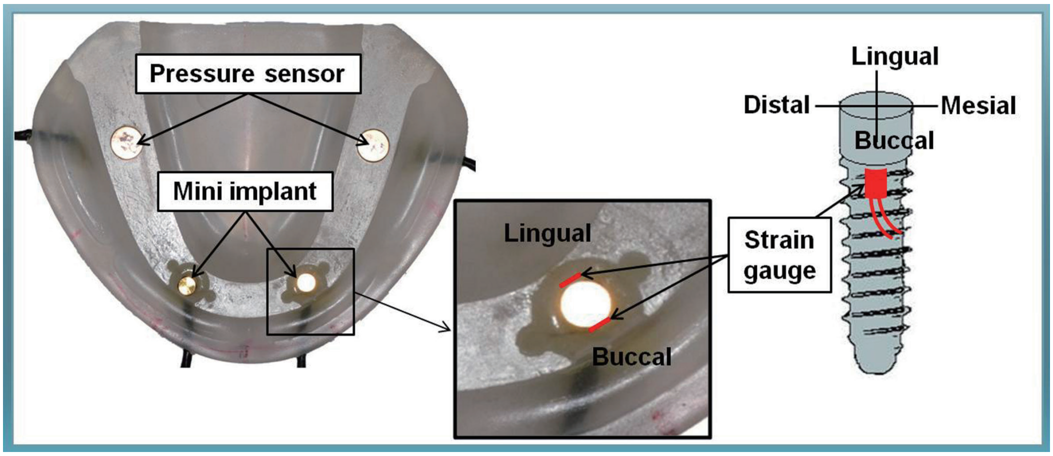

Fig. 1. Location and direction of the strain gauges surrounding the mini implants (MIs, Φ2.6 mm x 10 mm) on the mandibular simulation model.

sumption that it is between the lateral incisor and canine. Two exclusive keepers (Flat type, Aichi Steel Corporation, Aichi, Japan) were screwed onto the MIs (Fig. 1).

To simulate clinical conditions of MBR around MIs after prosthetic treatment (resorption group), the alveolar bone around the MIs of one model was resected 5 mm from the implant platform so that the upper halves (5 mm) of the MIs were exposed and only the lower halves were embedded in the alveolar bone (Fig. 2A). In another model, the full lengths of the MIs were embedded in the alveolar bone at the standard level (10 mm) to simulate clinical conditions without peri-implant alveolar bone loss (normal group) (Fig. 2B). The two experimental simulation models used in this study were manufactured by the same machining technology and duplicated by identical mold. Besides, the device had high calibration precision and calibrated by engineers before testing. These measures ensured a high level of consistency between the two mandibular models (except for the bone level around the MI).

Two uniaxial miniature strain gauges (KFR-02N-120-C1-11, Kyowa Electronic Instruments Co., Ltd., Tokyo, Japan) were attached to the buccal and lingual sides of each MI surface using a 2-component epoxy adhesive (Cemedine High-Super, Cemedine Co., Ltd., Tokyo, Japan). The long axes of the strain gauges were parallel to the long axes of the implants. The foils of the strain gauges were oriented to the implants (Fig. 1). For the normal group, the strain gauges were attached at the collar of the implant surface, while at half of the implant length for the resorption group (regions marked by small red square in Figs. 2B and 2A). Namely, the strain gauges in both normal and resorption groups were attached at the interface between the MIs and the alveolar ridge crest. Two small pressure sensors (6.0 mm in diameter, PS-10KD, Kyowa, Osaka, Japan) were placed near the left and right first molars on the residual bone of both simulation models to measure the pressure distribution of the posterior alveolar ridge (Fig. 1).

The mandibular master cast was prepared with super-hardened stone (New Fujirock, GC Co., Tokyo, Japan) from the original simulation model. Wax dentures were fabricated to form an occlusion rim without denture teeth. The heat-cured denture base resin was then packed and polymerized according to the manufacturer's instructions. After deflasking, finishing, and polishing, 5 experimental dentures were completed. They were commonly used for three groups: the resorption group, normal group, and complete denture group (CD group). In two experimental groups (resorption group and normal group), the magnetic attachments were used as retainers, and the magnetic assembly was connected to the denture base with autopolymerized resin (Unifast III, GC Co., Tokyo, Japan). As a control, no MI was used to support the denture base in CD group (Fig. 2C).

A displacement sensor (DT-A30, Tech, Tokyo, Japan)

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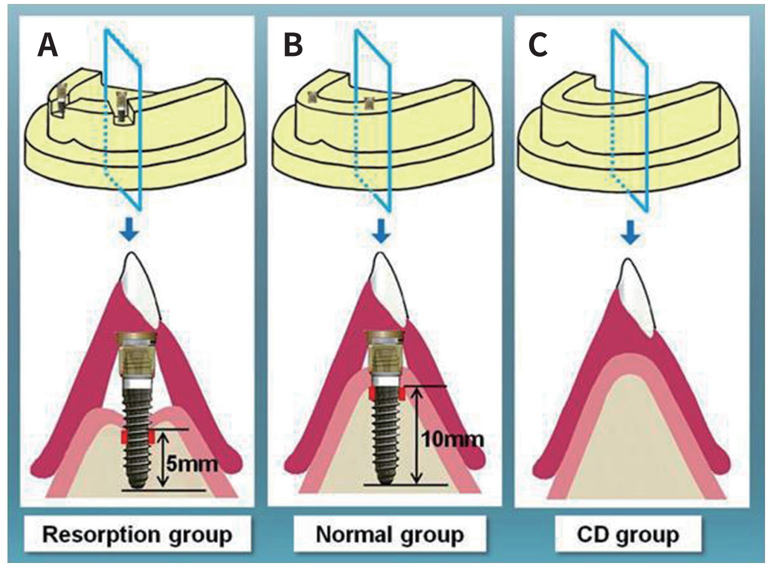

Fig. 2. Schematic drawing of three experimental conditions. (A) MI-OD with marginal bone resorption (MBR) to 1/2 the length of the implant (resorption group), (B) MI-OD without peri-implant MBR (normal group), (C) conventional complete denture (CD group). The small red squares on the MIs show the positions of the strain gauges.

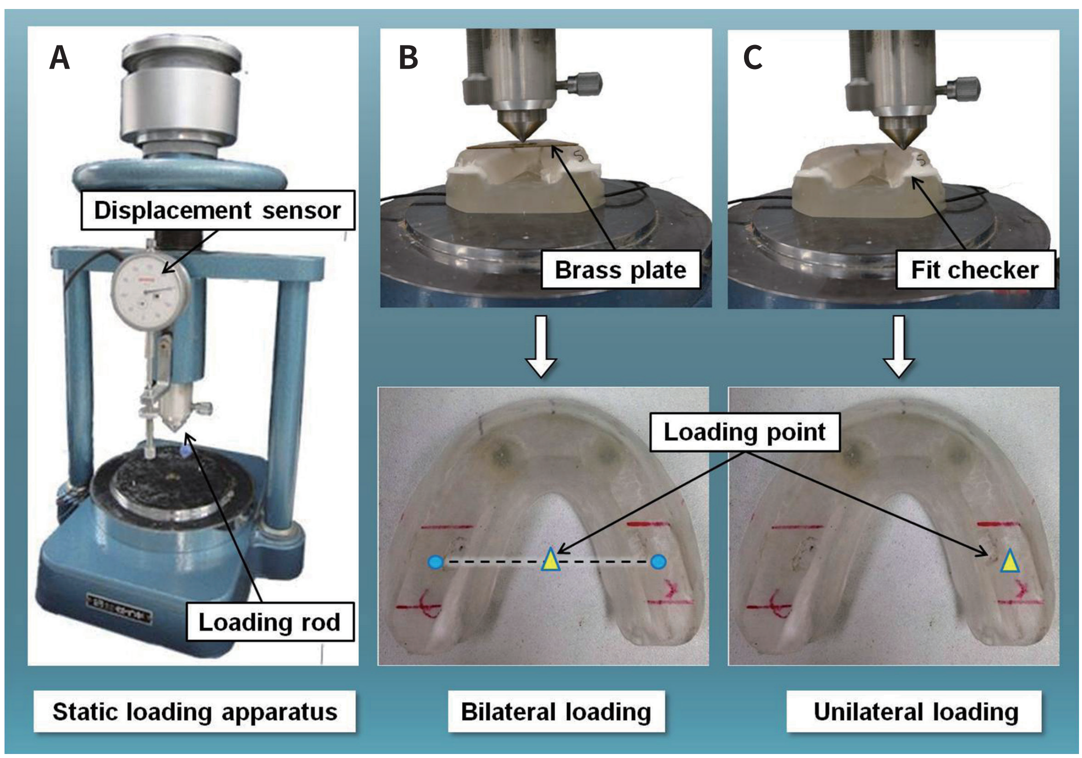

Fig. 3. Loading condition. (A) static loading apparatus equipped with displacement sensor and loading rod, (B) bilateral loading, (C) unilateral loading.

and a load cell (LM-20KA, Yokosawa, Tokyo, Japan) were set up on the loading rod in the static loading apparatus (Seiki, Tokyo, Japan) (Fig. 3A). Static loads of 50 N were applied bilaterally and unilaterally. For bilateral loading, a brass plate for vertical loading was attached to the occlusion rim of the experimental denture, and the load was applied at the midpoint of the line between the right and left pressure sensors at the first molar region (Fig. 3B). For unilateral loading, the load was exerted by the loading rod at the right first molar region on the occlusion rim of the experimental denture (Fig. 3C). Before loading, the loading rod contacted the brass plate (for bilateral loading) or the occlusion rim (for unilateral loading) lightly with-

Table 1. Study design

Groups	Loading conditions	Measuring items	No. of samples
Resorption	Bilateral Unilateral	Strain, pressure, displacement	5
Normal	Bilateral Unilateral	Strain, pressure, displacement	5
CD*	Bilateral Unilateral	Pressure, displacement	5

*CD: complete denture

out pressure. When a load was applied, the denture base was pushed down by the loading rod, and at the same time the displacement sensor recorded the max displacement of the loading rod, which was equal to the displacement of the denture base on loading point.

The strain in the buccal-lingual direction of the MIs, the pressure distribution on the alveolar ridge, and the displacement of the denture base were simultaneously measured using a sensor interface (PCD-300B, Kyowa, Osaka, Japan) and a personal computer (Dynabook T350/56AB, Toshiba, Tokyo, Japan). The data of strain (n = 5) were analyzed using the independent-samples t test, and the values of pressure (n = 5) and displacement (n = 5) were analyzed using a one-way analysis of variance (ANOVA) and a Tukey's multi comparison test (SPSS20.0, SPSS Inc., Chicago, IL, USA) at a significance level of α = .05 (Table 1).

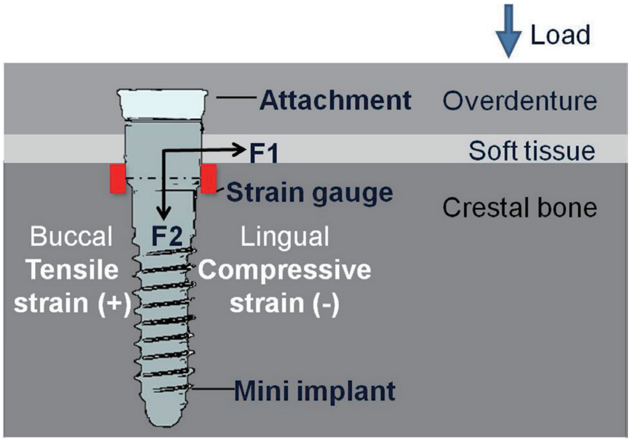

Fig. 4. Sketch of compressive and tensile strains occurring on the MI when loading was applied on the overdenture on simulation models. The resultant force acting on the MI is resolved into lateral (F1) and axial (F2) components. Lateral force induces tensile strain (+) on the buccal side and compressive strain (-) on the lingual side of the MI.

RESULTS

Strains around the implants during loading of the normal and resorption groups are shown in Figs. 5A and 5B. Fig. 4 illustrates that horizontal stresses produced tensile and compressive strains in the buccal and lingual sides of the MI, respectively. Of the bilateral load application, strain values around the right and left MIs were similar, and the absolute value of the strain in the buccal surface was almost equal to that of the lingual surface for each implant. The strain of each implant of the resorption group was approximately 1.5 times higher than that of the normal group. Both compressive and tensile strains in the resorption group were statistically greater than those in the normal group ($P < .05$) (Fig. 5A).

As compared with bilateral loading, the higher strains were observed around implants with unilateral loading on the loading side ($P < .05$), while there were lower strains on the non-loading side ($P < .05$) (Fig. 5B). On the loading side, both compressive and tensile strains were significantly larger in the resorption group than in the normal group ($P < .05$), while on the non-loading side, only compressive strains on MIs were significantly larger ($P < .05$). Nevertheless, buccal and lingual strains on MIs on the non-loading side were approximately 1/4 the values of those on the loading side.

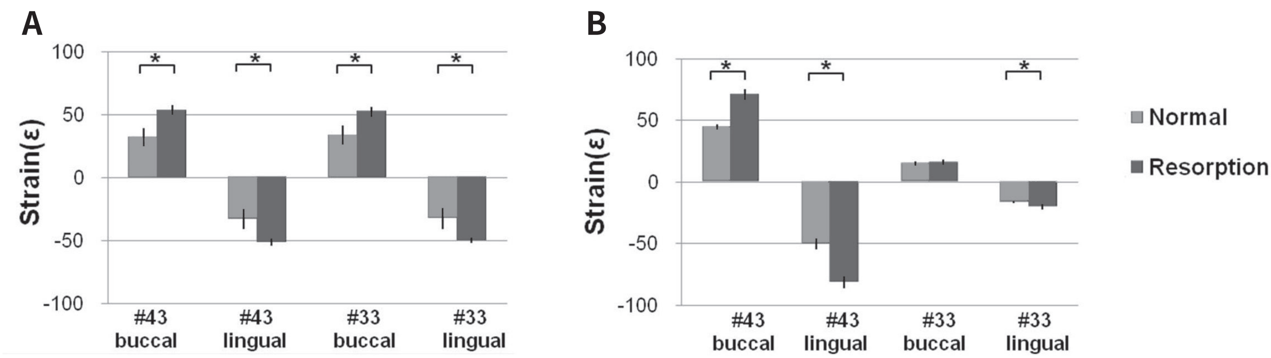

Fig. 5. Strain around the MIs for the Normal Group and the Resorption Group. (A) bilateral loading, (B) unilateral loading.

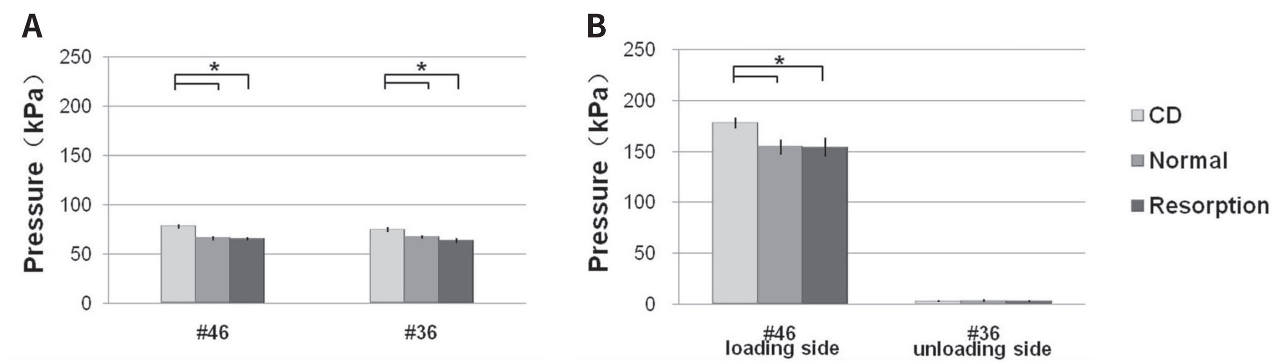

Fig. 6. Pressure values at the bilateral first molar regions among the 3 groups. (A) bilateral loading, (B) unilateral loading.

Pressure values on the bilateral first molar areas are shown in Figs. 6A and 6B. Regardless of the loading mode (bilateral or unilateral), the greatest pressure was obtained in the CD group. In bilateral loading, the pressure values on both sides were similar in each group. Although the pressure values in the CD group were significantly higher than in the MI-OD groups ($P < .05$), there was no statistical difference between the normal and resorption groups ($P > .05$) (Fig. 6A). Significantly greater pressure was obtained in the CD group than in the MI-OD groups ($P < .05$) on the loading side with unilateral loading. However, the pressure values on the right first molar area were more than 2 times greater as compared to those for bilateral loading for each group. Small pressures were measured at the non-loading side, and there was no significant difference among the three groups ($P > .05$) (Fig. 6B).

The denture displacements of CDs and MI-ODs during bilateral and unilateral loading are exhibited in Fig. 7. The CD group demonstrated greater displacement of the denture base than did the MI-OD groups during both bilateral and unilateral loadings ($P < .05$), similar to the pressure distribution tendency. Likewise, there was no significant difference between the displacement values of the normal and resorption groups ($P > .05$). When the loading condition was changed from bilateral to unilateral, the denture displacement was more than two times greater on the loading side in each group.

DISCUSSION

Although there is relatively little evidence-based research concerning the long term (beyond 10 years) performance of MIs for mandibular overdentutes,[3,23]

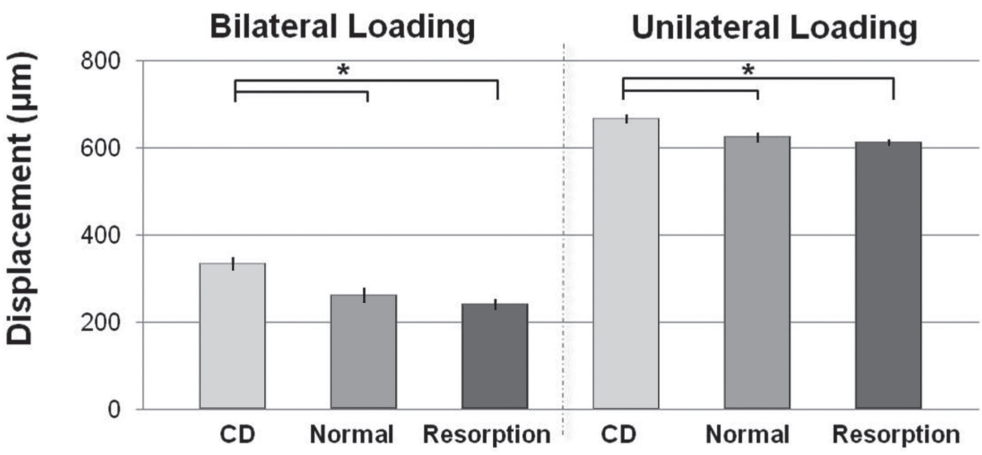

Fig. 7. Denture displacement among the 3 groups under bilateral/unilateral loading.

the effectiveness of MI systems with MBR was an issue of concern.[20,24] The focus of this *in vitro* study was to investigate the biomechanical effect of MBR on the strain of the MI and the support of the MI-OD. In view of the acceptable bone loss[15,17] and pathological bone loss, combining with the previous studies conducted by Linetskiy *et al*.[25] (assumed implants in 10+ years of service with 0.2 mm annual bone loss) and Leitão-Almeida *et al*.[26] (simulated narrow implants in 50% height of bone loss), the resorption group in the present study was simulated in the situation of MI with bone loss to 1/2 length to provide information especially for extreme bone loss cases. The location and direction of the strain gauge was also a crucial factor. For the MI in the present study, the bone wall of the implant in the buccal-lingual direction was thinner than that in the mesial-distal direction. Therefore, the implant was highly restricted by the thickness of alveolar bone in the buccal-lingual direction, and then the strain in this direction was a particular concern. The peak strains around implants are known to occur in the crestal bone around the osseointegrated implants.[27] In addition, the crestal bone around dental implant could be a fulcrum point for lever action when a bending moment is applied, suggesting that the marginal crestal bone could be more susceptible to loss by mechanical force.[28] The cortical bone is known to be least resistant to shear force, and the direction of the shear force is parallel to the interface of the implant and alveolar bone.[29] The strain gauge aligned parallel to the force direction recorded higher strain value than strain gauge aligned perpendicular to the applied force. Therefore, the strain gauges were attached parallel to the long axes of the implants, and the foils of the gauges were oriented to the implants in the present study.

A 3D finite element study showed that bone resorption progress reduced the contact area between the implant and the alveolar bone, and the stress transmitted to the peri-implant bone was increased.[30] The present results corroborated this finding. In our study, about 1.5 times higher strains in both sides were obtained in the resorption group under bilateral loading. However, unilateral loading induced considerable strains surrounding the MIs closest to the location of load application and lower strains surrounding the other MIs, and this gap was more pronounced in the resorption group. It seems that MIs with MBR near the loading side may potentially be more prone to suffer from overloading than other implants. Leitão-Almeida *et al*.[26] performed an *in vitro* study with narrow implants (3.5 mm) in a situation of 50% bone loss, which was similar to the resorption group in the present study. They concluded that increasing the clinical crown height significantly reduced the implant resistance to loading, and further led to the probability of fatigue fracture increased. Similarly, Romeed *et al*.[31] reported that implants with severe marginal bone

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loss are susceptible to mechanical failure. Based on the above point of view, practitioners should pay attention to appropriate treatment planning, special cautions of overstressing the MI-OD, and careful post-operative instructions, especially for hemimastication.

In bilateral loading, similar pressures were demonstrated on both sides by the symmetrical sagittal rotation of the denture base. Conversely, in unilateral loading, the denture base rotated frontally as a twist with slight pressure on the non-loading side. Greater pressures on the posterior ridge were shown in the CD group than in both MI-OD groups. According to Unsal *et al*.,[32] It was assumed that stresses were absorbed by the attachments and caused less stress transmission to the bone. Thus, MIs can provide effective support for overdentures and relieve the stresses on the posterior ridge, which were similar to conventional implants.[33,34] Consequently, it can be speculated that the tissue pain under the denture base would be prevented by MI placement. Similar pressures were observed in both the resorption and normal groups, which suggested that the MBR did not significantly jeopardize the supporting effect of the implant on the posterior alveolar ridge.

In terms of the strain surrounding the implants and the pressure distribution on the alveolar bone, the attachments played an important role. Comparing with other types of attachments, magnets have advantages that they can maintain a constant initial attractive force during maintenance period, and are small in size and easy to insert/remove.[35,36] However, in comparative studies of I-ODs with different attachments (magnetic, ball, round-bar, and locator) and CDs, some researchers[34] noted that although lower than those of CDs, oral mucosa pressure value was the highest when magnetic was employed, followed by locator and then ball. This was mainly due to the sinking of the overdenture with magnetic attachments. In this case, the magnetic structure is separated from the keeper, which resulted in posterior rotation of the dentures and increased the oral mucosa pressure on the posterior region. On the contrary, this similar stress-breaking effect in turn prevented the lateral overload on the implants.[37] In agreement with this theory, Takahashi *et al*.[38] reported that magnetic attachments caused the least amount of implant strain, while ball attachments caused the greatest, regardless of implant number and distribution. Therefore, magnetic attachments appeared to be superior in terms of implant stress. MIs were especially susceptible to the stress due to the reduced contact area.[39] For this reason, the magnet may be the most appropriate attachment system for the purpose of reducing the stress generated in the peri-implant bone[37] and would match the MI exceedingly well as attachments for overdentures, especially when MBR has occurred.

In the present study, the smaller denture displacement of the MI-OD groups as opposed to those of the CD group can lead to considerable improvement and stabilizing the dentures, as previously reported by studies of standard-sized implants.[33] Similar to this study, Shahmiri *et al*.[40] measured denture movements and reported that more lateral displacement was generated simultaneously under unilateral loading. From this point of view, bilateral balanced occlusion is suggested for MI-OD to evenly distribute forces on the posterior alveolar ridge, and thus reduce the movement of the denture base.[32] Therefore, suitable occlusal contacts must be constructed and managed to avoid overloading of the stress transmitted to the alveolar bone and to reduce the displacement of the denture base.

The limitation of this study is that because loading was applied only vertically, the retention of the denture, bracing effectiveness of the implant, and lateral movements of the denture base could not be apparently confirmed. To overcome this limitation and simulate more reasonable oral environment, further study including more loading type is needed.

CONCLUSION

To assess MBR on MI-ODs, the strain on the MI, the pressure on the soft tissue, and the denture displacement were measured on a simulated fully edentulous mandibular model. Within the limitations of this study, the following conclusions were drawn: first, the strain in the buccal-lingual bone of the MI with severe MBR (to 1/2 length of MI) was approximately 1.5 times higher than that without MBR. Second, significant decrease on posterior alveolar ridge pressure value and less displacement of the denture base were observed when MI-OD was applied, compared with CD, even when MBR occurred. Finally, the strain and pressure distributed more symmetrically and uniformly under bilateral loading. Therefore, bilateral balanced occlusion would be favorable in the cases of MI-ODs, especially when MBR occurred.

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