Mandibular two-implant overdentures should be the first-choice standard of care for completely edentulous patients. Bone resorption around the implant is considered to be the most important criterion for implant success or failure. Overload and inflammation seemed to enhance bone resorption around the implant. Although overload did not negatively affect osseointegration in an uninflamed environment around the implant according to several animal studies, most researchers concurred that overload in the existence of inflammation aggravates the plaque-induced bone resorption. Therefore, it is essential to pay attention to excessive force around implants in addition to plaque-induced inflammation.

Effect of Posterior Residual Ridge Resorption and Relining for Mandibular Implant Overdentures on Bending Strain Around Implants

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Purpose: To examine the influence of posterior residual ridge resorption (PRRR) and relining on bending strain around implants under an overdenture. Materials and Methods: Maxillary and mandibular edentulous models were made and covered with white silicone. Four strain gauges were placed on four sides of each implant. Two tissue-level implants were placed bilaterally in the part between the lateral incisors and canines of the mandible. A maxillary conventional denture and a mandibular overdenture were fabricated to fit the models. Three levels of bone resorption around the implant were created: 0, 0.8, and 1.5 mm. The surface of the residual ridge was uniformly removed from the area near the distal side of the implant to the retromolar section, and three levels of PRRR were created (0, 1, and 1.5 mm). After the measurement, the experimental denture of the PRRR of 1 mm and 1.5 mm were relined. Locator attachments were used. A 98-N occlusal force was applied, and bending strains around the implant were measured. The Kruskal-Wallis test and Bonferroni correction were employed to analyze the data. Results: Without relining, at each bone resorption level around the implant, the bending strain was smallest with PRRR of 0 mm and largest with PRRR of 1.5 mm. The bending strain after relining was smaller than the bending strain with ridge resorption. Bending strains after relining were smaller than bending strains with no ridge resorption, but there was no significant difference in bending strain between these three groups. Conclusion: As PRRR increased, the bending strain increased without relining. As bone resorption around the implant progressed, PRRR enhanced the increase in the peri-implant bending strain. Bending strain was reduced when relining was performed. Int J Oral Maxillofac Implants 2022;37:49–56. doi: 10.11607/jomi.9193

Keywords: bending strain, bone resorption around implant, implant overdenture, posterior residual ridge resorption, relining

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In the mechanical perspective, peri-implant bending strain (or bending strain) has been shown to increase as bone resorption around the implant progresses, and excessive bending strain also accelerates bone resorption. Thus, to minimize overload on interfaces between the bone and implant and to provide longitudinal stability of implants, the bending strain around implants should also be controlled.

Most studies have focused only on bone resorption around the implant, but studies investigating posterior residual ridge resorption (PRRR) reported significant atrophy in two-implant overdentures. The average PRRR rate has been recorded as 0.5 to 1 mm in 5 years and 1.5 mm in 10 years. The estimated mean PRRR is approximately 1 mm in 5 years. This resorption rate depends on general health status and might be more severe in some cases.

Currently, there is little information about the influence of PRRR on bone resorption around the implant. One clinical study indicated that bone resorption around the implant and PRRR occurred simultaneously after a 5-year follow-up. The influence of PRRR on bending strain around the implant is still unclear, and the influence of relining on bending strain around the implant has not been examined.

Therefore, the purpose of this model study was to determine the influence of PRRR and relining on bending strain around the implant under an overdenture. The first null hypothesis was that there would be no significant difference in bending strain between no PRRR and PRRR of 1 mm and 1.5 mm. The second null hypothesis was that there would be no significant difference in bending strain between no PRRR and following relining.

**MATERIALS AND METHODS**

**Model Fabrication and Validation Experiment**

The models and dentures were fabricated using the same method and materials as in the present authors’ previous study. First, four strain gauges (KFG-1N-120C1-11L1M2R, Kyowa Electronic Instruments, 4.8 mm in length × 2.4 mm in width) were placed on four sides of each implant (Fig 1). Edentulous maxillary and mandibular models (G2-402U and G2-402L, Nissin) were made with polymethyl methacrylate (Palapress Vario, Heraeus-Kulzer) and covered with white silicone (Fit Checker, GC) to simulate mucous membrane (2- to 4-mm thickness; Fig 2). Next, two tissue-level implants (4.1 mm in diameter × 10 mm in length, Straumann) were placed bilaterally in the part between the mandibular canines and lateral incisors (Fig 2). A maxillary conventional denture and mandibular overdenture were made to fit the edentulous models. The models were mounted on an articulator (Pro Arch IIG, Shofu; Fig 2). A validation experiment was confirmed with an in vivo study by Hotta and Sekine as described in the present authors’ previous study.
Calibration Experiment
Five loadings (0.98, 1.96, 2.94, 3.92, and 4.9 N) were applied perpendicularly to the implant at a distance of 4 mm from the implant neck. The bending strain was measured 10 times in each direction (buccolingual and mesiodistal), and calibration lines were created (Fig 3). Correlation coefficients of two directions were close to 1. This indicated a high correlation between the load and bending strain.

Bone Resorption Levels Around Implant
As described in the present authors' previous study, three levels of bone resorption were prepared sequentially around each implant: 0, 0.8, and 1.5 mm (Fig 4). Bone resorption around the implant was bilateral on both sides of the mandible.

Posterior Residual Ridge Resorption Levels
Three levels of PRRR (0, 1, and 1.5 mm) were set in the same model (Fig 5). First, from the original model (0 mm), 1 mm of the resin of the posterior ridge (from the area near the distal side of the implant to the retromolar section) was uniformly removed with a 1-mm-diameter bur. The resin on the anterior ridge was kept intact to focus only on the posterior ridge. After the simulated mucous membrane of the PRRR 0-mm level was removed, the new simulated mucous membrane with the same thickness was made to fit the PRRR 1-mm level. Exahiflex Adhesive (GC) was used to fix the simulated mucous membrane to the mandibular ridge. Next, after removing the simulated mucosa of the PRRR 1-mm level, a 0.5-mm-diameter bur was used to create the PRRR 1.5-mm level, and the simulated mucosa was made to fit the PRRR 1.5-mm level.

Reline Process
After measuring the bending strain in the PRRR 1-mm and 1.5-mm levels, a relining procedure (direct technique) was performed using the Kuraray base kit (Kuraray Noritake Dental; Fig 5).

Loading Condition
A 98-N occlusal force was applied through the maxillary complete denture, as shown in the present authors' previous study (Fig 2).

Attachment Type
A locator attachment (blue type, regular neck, 3-mm abutment height, Ø4.8 mm, Zest Anchors) was used (Fig 5b). A denture cap was placed in the denture base with polymethyl methacrylate (Unifast III, GC).
Each measurement of bending strain was recorded for 10 seconds, five times, as described in the present authors’ previous study. Strain gauges were connected to a sensor interface (PCD-400A, Kyowa Electronic Instruments) controlled by a laptop computer (Dynabook Satellite B552/H, Toshiba) to measure the bending strain in the mesial-distal [Mx] and buccal-lingual [My] directions. The square root of sum of squares of bending strain in these directions was calculated to combine them in each condition.

**Experimental Measurement**
Each measurement of bending strain was recorded for 10 seconds, five times, as described in the present authors’ previous study. Strain gauges were connected to a sensor interface (PCD-400A, Kyowa Electronic Instruments) controlled by a laptop computer (Dynabook Satellite B552/H, Toshiba) to measure the bending strain in the mesial-distal [Mx] and buccal-lingual [My] directions. The square root of sum of squares of bending strain in these directions was calculated to combine them in each condition.

**Statistical Analysis**
Bending strains were compared among the three PRRR levels and relining for 1-mm and 1.5-mm PRRR in each level of bone resorption around the implant. The Kruskal-Wallis test and Bonferroni test for multiple comparison were conducted with SPSS 20.0 (IBM). A *P* value of .05 was considered statistically significant.

**RESULTS**

**Difference in Bending Strain When PRRR Occurred Without Relining**
At a bone resorption around the implant 0-mm level, the bending strains with PRRR 0, 1, and 1.5 mm were $130 \times 10^{-6}$, $170 \times 10^{-6}$, and $200 \times 10^{-6}$, respectively (Fig 6 and Table 1). The bending strain was smallest with PRRR of 0 mm and largest with PRRR of 1.5 mm among the three levels of PRRR (*P* < .05). The bending strain with PRRR of 1.5 mm was 1.5 times larger than the bending strain with PRRR of 0 mm (*P* < .05). As PRRR increased, the bending strain increased when relining was not performed.

At bone resorption around the implant 0.8-mm and 1.5-mm levels, similar results were obtained (Fig 7 and Table 2; Fig 8 and Table 3). At bone resorption around the implant 0.8-mm level, the bending strain with PRRR of 1.5 mm ($280 \times 10^{-6}$) was 1.65 times larger than the
bending strain with PRRR of 0 mm (170 × 10⁻⁶; P < .05). At the peri-implant bone resorption 1.5-mm level, the bending strain with PRRR of 1.5 mm (350 × 10⁻⁶) was 1.75 times larger than the bending strain with PRRR of 0 mm (200 × 10⁻⁶; P < .05). When bone resorption around the implant occurred, the bending strain increased as PRRR increased. In other words, as bone resorption around the implant progressed, PRRR enhanced the increase in bending strain.

**Difference in Bending Strain After Relining**

At bone resorption around the implant 0-mm level, the bending strain with PRRR of 1 mm after relining (120 × 10⁻⁶) was significantly smaller (approximately 1.5 times) than the bending strain with PRRR of 1 mm (170 × 10⁻⁶; P < .05). The bending strain with PRRR of 1.5 mm after relining (115 × 10⁻⁶) was approximately half the bending strain with PRRR of 1.5 mm (200 × 10⁻⁶; P < .05; Fig 6 and Table 1). At bone resorption around the implant 0.8-mm and 1.5-mm levels, similar results were obtained (P < .05; Fig 7 and Table 2; Fig 8 and Table 3).

At bone resorption around the implant 0-mm level, bending strains with PRRR of 1 mm after relining and PRRR of 1.5 mm after relining were smaller than the bending strain with PRRR of 0 mm, but there was no significant difference in bending strain between these three groups (Fig 6 and Table 1). At bone resorption around the implant 0.8-mm and 1.5-mm levels, similar results were obtained (P > .05; Fig 7 and Table 2; Fig 8 and Table 3).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Probability Values of Multiple Comparisons Between Different Levels of PRRR and After Relining (Bone Resorption Around Implant at 0.8-mm Level)</th>
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<tr>
<td>PRRR 0 mm (130 × 10⁻⁶)</td>
<td>PRRR 1 mm (170 × 10⁻⁶)</td>
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<td>PRRR 0 mm (130 × 10⁻⁶)</td>
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<tr>
<td>PRRR 1 mm (170 × 10⁻⁶)</td>
<td>.02*</td>
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<tr>
<td>PRRR 1.5 mm (200 × 10⁻⁶)</td>
<td>.04*</td>
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<td>1 mm after relining (120 × 10⁻⁶)</td>
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<tr>
<td>1.5 mm after relining (115 × 10⁻⁶)</td>
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*Statistically significant (P < .05).

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<tr>
<th>Table 3</th>
<th>Probability Values of Multiple Comparisons Between Different Levels of PRRR and After Relining (Bone Resorption Around Implant at 1.5-mm Level)</th>
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<tbody>
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*Statistically significant (P < .05).
DISCUSSION

This study examined the influence of PRRR and relining on bending strain around implants under an overdenture. The results revealed that as PRRR increased, bending strain increased without relining. The first null hypothesis (that there would be no significant difference in bending strain between no PRRR and PRRR of 1 mm and 1.5 mm) was rejected. Moreover, as bone resorption around the implant progressed, PRRR enhanced the increase in bending strain. Bending strain around the implants was reduced after relining. Finally, there was no significant difference in bending strain after relining and no resorption. Thus, the second null hypothesis (that there would be no significant difference in bending strain between no PRRR and following relining) was not rejected.

For model fabrication, polymethyl methacrylate and silicone material have been reported to be suitable materials for mechanical simulation of the mandible in various experimental studies. In this experiment, it was crucial to measure all experimental conditions with the same sensors (strain gauges) to avoid measurement variation. Regarding the model condition, this model was class III in the Cawood classification system. Regarding bone type, Young’s modulus of acrylic resin (3 GPa) was between Young’s modulus of D2 (5.5 GPa) and D3 bone (1.6 GPa). Moreover, acrylic resin (2,700 MPa) was twice as hard compared with cancellous bone (1,370 MPa) and less hard than cortical bone (13,700 MPa).

Levels of 1 mm and 1.5 mm were chosen for PRRR, because the average rate of PRRR is reported to be 1 mm in 5 years and 1.5 mm in 10 years. Instead of grinding the inner surface of the denture, the posterior ridge was ground to simulate clinical conditions. Additionally, the simulated oral mucosa was made for each PRRR level with the same thickness to ensure consistency under various experimental conditions.

Without relining, an increase in denture movement without mucosal support can increase the bending strain. The overdenture rotated freely around the axis made by the two attachments before contacting the mucosa, and this movement could have transferred stress to the implants. Therefore, the bending strain was increased without relining. An ill-fitting overdenture not only causes mucosal wounds, denture instability, and occlusal contact problems, but also increases bending strain, which may affect the implant. To prevent further bone resorption around the implant, it is crucial to regularly check the fit of the denture.

Without relining, as bone resorption around the implant progressed, the PRRR enhanced the increase in bending strain. This can refer to the combination of the increased denture movement without mucosal support (caused by PRRR) and the principle of leverage (caused by bone resorption around the implant). The more severe the bone resorption, the larger the bending strain. A larger bending strain accelerates the risk of bone resorption around an implant.

After relining, a smaller bending strain was recorded because the vertical space between the overdenture and beneath the mucosa was eliminated. By relining, the mucosa can directly support the overdenture and distribute the occlusal load throughout the residual ridge, thus reducing the bending strain.

Bone around the implant surface went through the remodeling process to adapt to stress, which was confirmed by the existence of medullary or marrow spaces surrounding the implant with various types of cells. To a certain extent, bone formation was enhanced by mechanical loading. Sugiura et al mentioned that bone resorption occurred if the bone strain reached 3,600 με. Although loading in this experiment was 98 N, the occlusal force of patients wearing implant overdentures can reach 305.5 N. Moreover, bending strain was recorded to be twice as large with nonaxial loading compared with axial loading. Therefore, peri-implant bone might have a larger bending strain in clinical condition. When peri-implant inflammation is present, overload can accelerate bone resorption, although it did not reach the bone resorption threshold. Bone resorption may occur at a smaller strain; therefore, it is necessary to control bending strain to prevent bone resorption.

The results of this experiment emphasize the importance of periodic checking of the denture fit to lessen the risk of further bone resorption around the implant. The present findings once again emphasize the necessity of relining to minimize the bending strain around implants during maintenance of an overdenture.

Limitations

The main limitation of this study was the difficulty of simulating oral conditions on a model. For example, the rigid model was homogenous with acrylic resin, while the mandible was heterogenous with two bone layers (different thickness and highly porous). Nevertheless, the design and experimental conditions were replicated to a feasible extent. Sato showed that the elastic modulus of acrylic resin is similar to cancellous bone, and acrylic resin was also reported to be a suitable material for the mechanical simulation of the mandible. The characteristics of Fit Checker can be nearly similar to the oral mucosa. In this experiment, the same systems (the implant type and dentures, embedded...
positions) were used as in the oral cavity. The loading amount was also similar to a real clinical situation.

Moreover, to testify whether this model is similar to the oral condition, a validation experiment was conducted, and those results were compared with an in vivo study by Hotta and Sekine. Therefore, these results can contribute to biomechanical conclusions about the influence of PRRR and relining on the bending strain around implants.

CONCLUSIONS

From the study, the following conclusions were drawn:

1. As PRRR increased, bending strain increased without relining.
2. When bone resorption around the implant occurred, PRRR enhanced the increase in bending strain.
3. When bone resorption around the implant and PRRR has occurred, relining can reduce the bending strain around the implant.
4. There was no significant difference in bending strain between no resorption and after relining.

When bone resorption has progressed around implants, relining was needed after long-term use, attention should be paid carefully to PRRR, with frequent checks of denture fit as a routine maintenance procedure.

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