STRAIN ON THE LABIAL PLATES AROUND ABUTMENTS SUPPORTING REMOVABLE PARTIAL DENTURES WITH VARIOUS PROSTHETIC DESIGNS: AN *IN VITRO* STUDY

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Statement of problem. In distal extension removable partial denture, the preservation of health of abutment teeth is very important, but abutment teeth are subjected to unfavorable stress.

Purpose. The purpose of this study was to investigate the biomechanical effects of mandibular removable partial dentures with various prosthetic designs using strain gauge analysis.

Material and methods. Artificial teeth of both canines were anchored bilaterally in a mandibular edentulous model made of resin. Bilateral distal extension removable partial dentures with splinted and unsplinted abutments were fabricated.

Group 1 : Clasp-retained mandibular removable partial denture with unsplinted abutments

Group 2 : Clasp-retained mandibular removable partial denture with splinted abutments by 6-unit bridge

Group 3 : Bar-retained mandibular removable partial denture

Strain gauges were bonded on the labial plate of the mandibular resin model, approximately 2 mm close to the abutments. Two vertical experimental loadings (100N and 200N) were applied subsequently via two miniature load cells that were placed at mandibular first molar regions. Strain measurements were performed and simultaneously monitored from a computer connected to data acquisition system. For within-group evaluations, t-test was used to compare the strain values and for between-group comparisons, a one-way analysis of variance (ANOVA) was used and Duncan test was used as post hoc comparisons.

Results. Strain values increased as the applied load increased from 100N to 200N for all groups ($p<.05$). The strain values of group 1 and 2 were tensile under loadings. In contrast, strain values of group 3 were compressive in nature. Under 100N loading, group 1 showed higher strain values than group 3 in absolute quantity ($p<.05$). Under 200N loading, group 3 showed higher strain values than group 1 and 2 in absolute quantity ($p<.05$). Group 1 showed higher strain values than group 2 ($p<.05$).

Conclusion. Splinting of two isolated abutments by bridge reduced the peri-abutment strain in comparison with unsplinted abutments. Strain of bar-retained removable partial denture increased much more as applied load increased, but was compressive in nature.

Key Words
Abutment, Removable Partial Denture, Biomechanics, Strain gauge

As for the distal extension removable partial denture, the loads to be given to the abutments were very important because most of strain was delivered in the off-vertical direction, which was disadvantageous to the abutments. There were several ways to judge whether a distal extension removable partial denture was successful or not, but it was very important to keep the abutment and the residual alveolar ridge healthy. For successful remedy with the distal extension removable partial denture, efforts have been taken to disperse strain widely to keep abutments and other dental tissues healthy.[1]

Many researches to solve the problems with the distal extension removable partial denture have been carried out. In relation to the researches about direct retainer designs to reduce strain, it was studied that the leverage effects of abutments by the locations of clasp and occlusal rest,[2] and the effects of Akers clasp at holography study.[3] It was studied that the movements of teeth when RPI clasp was used[4] and the effects of combination clasp for distal extension removable partial denture.[5]

In order to disperse the strain that was given to the abutment, the abutment and its adjacent teeth were splinted for the distal extension removable partial denture. In the researches of movements of the splinted abutment, it was reported that mesio-distal force and movements of the bucco-lingual portion were reduced quite much, but there was no change in the vertical movement of the abutment.[6] Carlsson et al.[7] proposed abutment splinting for removable partial denture. And it was reported that how to splint the adjacent abutment was an important factor for distal extension removable partial denture when attachment retainer was used.[8] It was reported that the abutments of the distal extension partial denture, which were periodontally weak and moved, should be splinted.[9] However, there were many arguments over splinting natural teeth that were periodontally strong. Splinting was not applicable to the patients who took healthy chewing activities, having normal periodontal ligament and little movements of teeth.

Denture designs in case of remaining canines could be divided into the partial denture and overdenture; those could be classified again, depending on whether the splinting device for abutments was used or not, and on whether an additional device like attachment was used for abutments.[10] Removable partial dentures have been used a lot because of convenience and of economic advantage, therefore, considerations how to efficiently disperse strain of the removable partial denture to abutments and residual alveolar ridge, and how to keep the abutments healthy were needed.

In comparison with fixed prosthesis, force acting on abutment supporting removable partial denture has claimed to increase the magnitude of moments. Particular interests, therefore, have been given to the influence of different prosthetic designs on strain magnitudes around abutment supporting removable partial denture. *In vivo* studies, unfortunately, were insufficient to derive constitutive descriptions concerning biomechanical environment in bone tissue around abutments as measurements were carried not only above bone level, but also on prosthetic abutments, which do not represent the biomechanical characterization of living bone.[11] Overall, it is noteworthy that controversy and lack of consensus still remains on intra osseous strain levels around splinted and unsplinted abutments supporting removable partial denture. Nevertheless, high success rates of mandibular removable partial denture supported by canines might suggest that high bone quality in the mandibular anterior region and decreased occlusal bite forces in elderly patients allow force distribution around abutments within physiologic levels.

This study intended to examine the influence of the methods of abutment splinting for the distal extension removable partial denture. For this, it has employed different designs of splinting and used strain gauge analysis to examine the pattern of strain that was shown on the labial plate around abutment. The purpose of this study was to investigate the biomechanical effects of mandibular removable partial dentures with various prosthetic designs using strain gauge analysis.

MATERIAL AND METHODS

1. Fabrication of experimental mandibular model and removable partial dentures

An edentulous mandibular acrylic resin model (Vertex SC, Dentimex, Zeist, Netherlands) was fabricated. On this model, anterior teeth were arranged according to the guidelines[12] established for fabricating complete dentures to determine canine locations. Indicator marks representing canines were placed bilaterally. Following the removal of artificial teeth, the model was placed on the surveying table of a milling machine to prepare sockets. Artificial teeth of both canines (A5-500B, Nissin Dental Products Inc., Tokyo, Japan) were anchored into the sockets bilaterally. A 2-mm-thick layer was removed from the denture-supporting surface of the resin model and then replaced with polyvinylsiloxane impression material (Examix, GC corp., Tokyo, Japan) to simulate resilient edentulous ridge mucosa. Canines were prepared according to preparation guides. Surveyed two porcelain fused to metal crowns, a 6-unit porcelain fused to metal bridge and a bar (Hader bar, Cookson Co., La Chaux-de-Fonds, Switzerland) for abutments were fabricated. The removable partial dentures used in this study were classified as follows (Fig. 1):

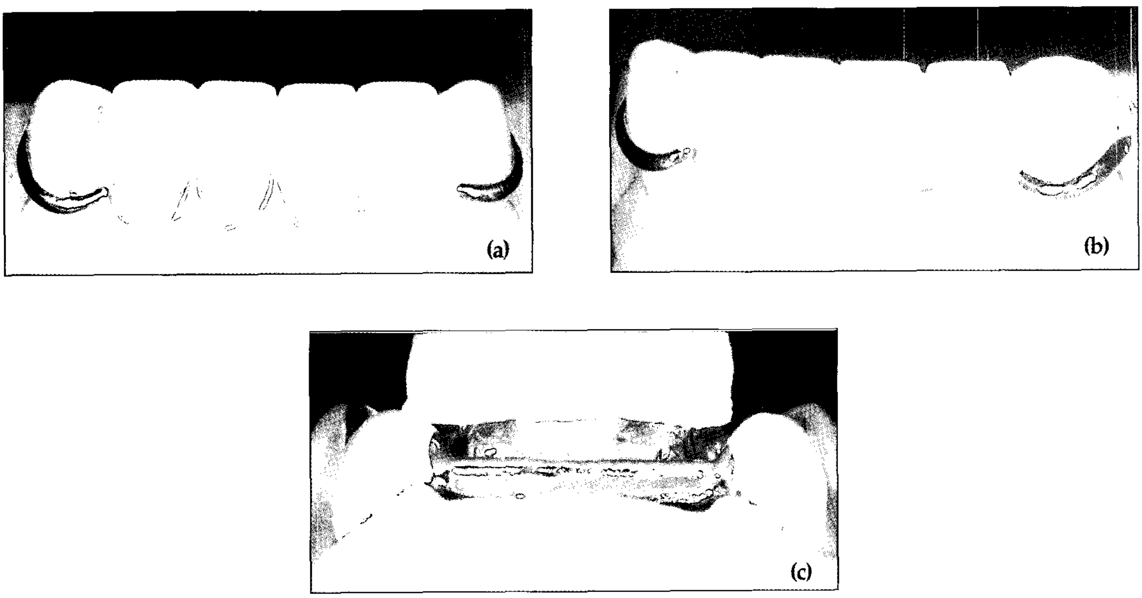

Fig. 1. Close view of the removable partial dentures placed over the crown-retainer (a) and the bridge-retainer (b), and prior to placement over the bar-retainer (c).

Group 1 : Clasp-retained mandibular removable partial denture with unsplinted abutments

Group 2 : Clasp-retained mandibular removable partial denture with splinted abutments by 6-unit bridge

Group 3 : Bar-retained mandibular removable partial denture

Clasp- and bar-retained removable partial dentures were fabricated and processed according to the principles established for processing removable partial dentures. RPA clasps were used for clasp-retained removable partial dentures. Three sets of removable partial dentures were fabricated for each case. Jigs were fabricated at bilateral first molar regions to house miniature load cells (CSMN-50L, Curiosity Technology, Seoul, Korea) for controlled experimental static loading. The load cells were connected to digital weight indicators (CTI-1100A, Curiosity Technology, Seoul, Korea).

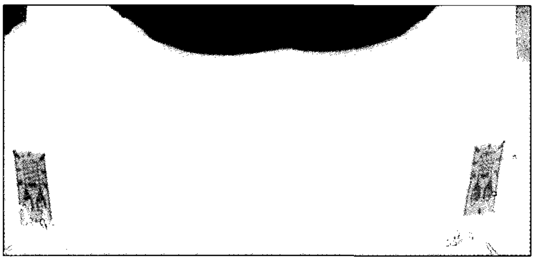

Fig. 2. The linear strain gauges bonded on the labial plates around abutments.

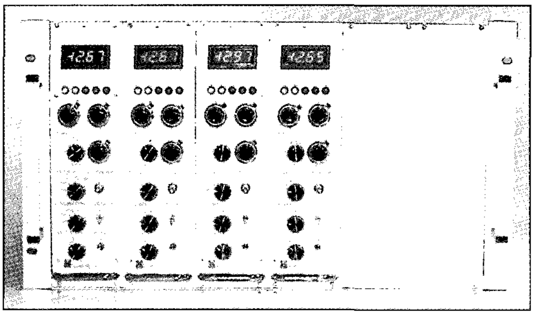

Fig. 3. Dynamic signal conditioning strain amplifiers.

2. Quantification of strain

Linear strain gauges (120 Ω; gauge length 1 mm; KFG-1-120-C1-11, Kyowa, Japan) were bonded on the labial plate of the mandibular resin model, approximately 2 mm close to the abutments (Fig. 2).[13] The strain gauges were bonded with a special cyanoacrylate (M-Bond200, Vishay Micro-Measurements, Raleigh, NC, U.S.A.). The lead foils of the gauges were connected to bridge boxes (CTB-100, Curiosity Technology, Seoul, Korea) via terminals. Each gauge was wired separately into a Wheatstone bridge. The wires of the gauges were waterproofed by application of the air drying polyurethane (MCoatA, Vishay Micro-Measurements, Raleigh, NC, U.S.A.). The strain gauges were then connected to cables. The cable led the signals to a dynamic signal conditioning strain amplifier (CTA-1000, Curiosity Technology, Seoul, Korea) (Fig. 3) that was used to supply an excitation voltage in the Wheatstone bridge, thereby improving the signals. Two vertical experimental loadings (100N and 200N) were applied subsequently via two miniature load cells that were placed at mandibular first molar regions (Fig. 4). The analog signals of electric

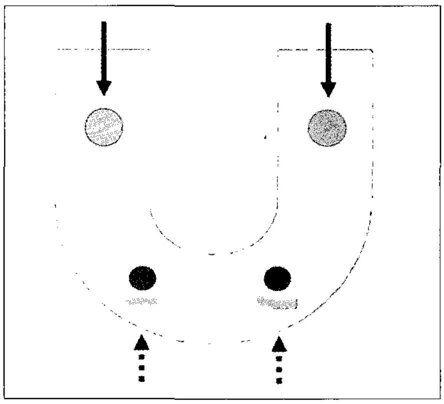

Fig. 4. Measuring devices. Lined arrows indicate the loading points and dotted arrows indicate the strain gauges.

resistance variation were converted into digital signals via a 16 byte resolution converter (DAQCard-A1-16XE-50, National Instruments, Austin, U.S.A.) and processed by custom software (DA-1700B, Cas Korea, Seoul, Korea). Channel signals were originally measured in millivolt and then converted to microstrain units (μm/m). Measurement capability was 1 μm/m. Ten measurements at each load were made under the same conditions, allowing at least 5 minutes for recovery. Each experiment was repeated on three sets of three different typed removable partial dentures.

3. Statistical analysis

For within-group evaluations, *t*-test was used to compare the strain values. For between-group comparisons, a one-way analysis of variance (ANOVA) was used to assess the differences and Duncan test was used as post hoc comparisons.

RESULTS

The strain values produced from bilateral strain gauges were compared with each other by t-test at 95% confidence level and non-significant difference between the strain values was assessed ($p>.05$). Strain values around the abutments supporting removable partial denture under 100N and 200N loadings were presented in Tables I, II (Fig. 5).

Within-group comparisons revealed that strain values increased as the applied load increased from 100N to 200N and the differences in strain values between two consecutive loadings were significant for each group ($p<.05$). Between-group comparisons showed that strain values of group 1 and 2 were tensile under 100N and 200N loadings. In contrast, strain values of group 3 were compressive in nature under 100N and 200N loadings. Under 100N loading, group 1 showed higher strain values than group 3 in absolute quantity ($p<.05$). The strain values of group 1 were higher than those of group 2, but were not significantly different. The strain values were not significantly different between group 2 and 3 in absolute quantity. Under 200N loading, group 3 showed

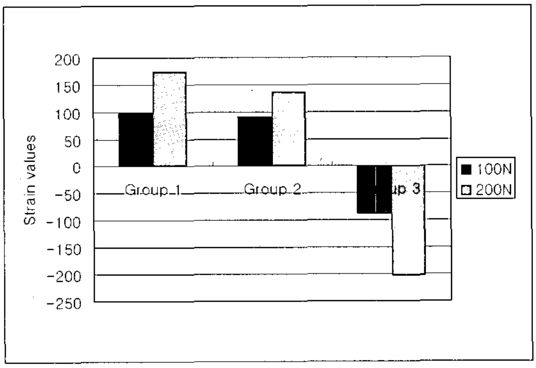

Fig. 5. Microstrain on the labial plates around abutments supporting mandibular removable partial denture under loadings.

Table I. Microstrain on the labial plates around abutments supporting mandibular removable partial denture under 100N loading

Group	Mean	S.D.
1	97.68	6.91
2	91.48	6.53
3	-88.38	12.03

S.D.: Standard deviation

Table II. Microstrain on the labial plates around abutments supporting mandibular removable partial denture under 200N loading

Group	Mean	S.D.
1	174.13	8.21
2	137.03	12.53
3	-202.83	20.06

S.D.: Standard deviation

higher strain values than group 1 and 2 in absolute quantity (p<.05). Group 1 showed higher strain values than group 2 (p<.05).

Splinting of two isolated canines by 6-unit bridge reduced the peri-abutment strain in comparison with unsplinted canines. Strain values of bar-retained removable partial denture increased much more as applied load increased than those of clasp-retained removable partial denture, but were compressive in nature. The minimum strain (74㎛/m) was recorded for Group 3 under 100N loading while the maximum strain (240 ㎛/m) was for Group 3 under 200N loading.

DISCUSSION

In case of distal extension removable partial denture that supported by teeth and oral surrounding structures, functional forces that were given when the denture worked were dispersed to the teeth and the supporting structure unlike partial denture supported by teeth only. Because of the differences in the histological characters of teeth and supporting structure, a fulcrum line was made centering around the backmost abutment when the functional force was given, and on its axis, denture base movement happened. The movement of the distal extension removable partial denture became a cause for making denture prognosis disadvantageous - the efficiency of the chewing function dropped or a patient got to feel uncomfortable. And furthermore, it made strain concentrated, which resulted in injuring health of the abutment or the residual alveolar ridge.

Strong retentive force caused more force to the abutment than small retentive force did. Adding an occlusal rest or splinting could give smaller force to the abutment than keeping small retentive force without rest or splinting. It was possible to disperse strain most evenly by having small retentive force, adding a rest for support, and splinting the abutment.[14] However, splinting the abutment required removal of healthy tooth structure, and it could interfere oral hygiene because of its wide splinting portion.[15] It could harmfully stimulate gingiva in case the marginal portion invaded it.[16] Therefore, to restrict the size of splinting could reduce these disadvantages. It has been generally known that reduction of strain on the abutment, which was made by occlusal force of the removable partial denture, was proportionate to the size of splinting. When a single abutment was used, undesirable horizontal force could get larger than that of the splinted abutment. In the strain analysis for abutment with different periodontal support applied, Itoh et al.[17] said that reduction of strain was not directly proportionate to the size of splinting in case of the normally supported abutment, and that on the other hand, if the backmost abutment, which was poor in terms of periodontal support, was splinted with other healthy abutment, the effect was great. The technique of splinting natural teeth was used for the purpose of treating the patients who had periodontal troubles. As for the patients who had progressive periodontitis, the purpose of splinting was to make movements of teeth normal or to prevent movements of teeth from increasing, and further to improve oral environment so that the patients could comfortably perform. The fixed crowns that were additionally splinted had an effect of substituting other damaged teeth.

In addition, there were researches of impression materials and impression techniques,[18] of strainbreaker[19] and of splinting device designs[20] for distal extension removable partial denture. Igarash et al.[21] mentioned that support in the mucous tissue, rather than design of retainer, was more important for the distal extension removable partial denture. For support of the residual alveolar ridge, Linke et al.[22] and Wang et al.[23] studied movements of partial dentures by the kinds of impression materials. Leupold et al.[24] used a modified cast impression technique to examine support of the mucous tissue. However depending on the location and the number of abutments, horizontal forces could arise. As denture saddles tended to function like a fulcrum, abutment received considerable bending moments transferred from the abutment into the bone.

In the field of prosthodontics, when both canines of the lower jaw remained, crown designs were various and strain on the residual alveolar ridge and the abutments could be different. Designing an ideal crown, which minimize any burden to the residual alveolar ridge and the abutment, was necessary. And according to the status of the supporting tissue around canines, the quantity and quality of the residual alveolar ridge, and the relationship with teeth, several treatment plans could be drawn up. The purpose of crown treatment, in case a small number of teeth remained, was to appropriately disperse strain of the abutment and the residual alveolar ridge in order to delay the edentulous status as possible as could and further, to preserve the function of the mouth as long as possible. Especially, canines were likely to remain to the end so to preserve canine teeth was very important in preventing the edentulous status and degenerative change of the lower jaw.

The load to be given to denture was delivered to abutment, surrounding alveolar bone and residual alveolar tissues of the denture muscle. Because of the difference in elasticity of alveolar periosteum and mucogingiva, distribution of strain happening in the denture muscle was various and analysis of strain by change in the denture design was very complicated.[25] By analyzing any change in strain distribution on the denture supporting areas, an ideal denture that performed its functions without giving any harm to abutment, tissues around teeth and other oral structure should be considered. If external force was given to an object, the distribution type of internal strain became different, depending on the direction of the force, and the shape and material of the object receiving the external force. This internal strain could cause transformation in the object and in case the strain was big, it could cause permanent transformation or destruction.[26] Especially, the lower jaw was very sensitive to this strain and was likely to cause degenerative change because its supporting areas were quite much reduced compared with that of the upper jaw, and the lower jaw in the edentulous status could not stand load better than the upper jaw in terms of its shape and structure. Therefore, in case both canine teeth remain in the lower jaw, it was significant to maintain and preserve the teeth.

Although the masticatory loads in mandibular removable partial denture are smaller than those in either the natural dentition or fixed restorations, removable partial denture is subject to both axial and transverse forces, the latter being smaller, but potentially more harmful. This study used the one-point concentration load, since it was almost impossible to reproduce crewing pattern by *in vitro* experiments. In this study, strain values of group 1 and 2 were tensile under 100N and 200N loadings. In contrast, strain values of group 3 were compressive in nature under 100N and 200N loadings. The difference of strain nature could be due to difference of retentive methods of removable partial denture. As for clasp-retained removable partial denture, pulling force happened on abutment under loadings. In contrast, as for bar-retained removable partial denture, pressing force happened on abutment via cingulum rest under loading. In this case, pulling force could happen at center of bar on that retentive clip mounted. The tensile stress on abutment could be more harmful. Strain values on labial plate around unsplinted abutment were higher in comparison with those of bridge-splinted abutment. Increased strain values around unsplinted abutment could be critical because occurring deformations could be close or even pass the tolerance that would be deleterious to abutment.

CONCLUSION

The purpose of this study was to evaluate the stress patterns developed around abutments supporting removable partial denture in case of remaining mandibular canines. The results were as follows:

1. Strain values increased as the applied load increased from 100N to 200N.
2. Strain values of clasp-retained removable partial denture were tensile under loadings. In contrast, strain values of bar-retained removable partial denture were compressive in nature.
3. Splinting of two isolated canines by bridge reduced the peri-abutment strain in comparison with unsplinted canines.
4. Strain values of bar-retained removable partial denture were higher than those of clasp-retained removable partial denture under 200N loading, but were compressive in nature.

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