Original Article

Influence of Loading Positions of Mandibular Unilateral Distal Extension Removable Partial Dentures on Movements of Abutment Tooth and Denture Base

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Purpose: The aim of our study was to explore the effects of different loading positions on the movements of the abutment tooth and denture base of removable partial denture with unilaterally designed framework (RPD-U). Materials and Methods: The experiment was carried out with a simulation model of a mandible without left molars. The movements of abutment tooth and denture base of the unilateral and bilateral designs were due to 30N vertical load on 12 loading positions determined with a strain gauge circuitry. The effects of loading positions on the movements of the abutment tooth and denture base were compared between two designs. Results: During the loading on buccal, lingual positions, and the most disto-central position the movements of the abutment tooth and denture base of the unilateral design were significantly greater than those of the bilateral design (P<0.01). During the loading on the three mesio-central positions the movements of the abutment tooth and denture base were equal between designs, and were significantly lower than during the loading on the other positions (P<0.01). Conclusion: Ending the denture teeth at the mesial cusp of second molar and positioning the occlusal contacts over the ridge crest adequately stabilize the abutment tooth and denture base of RPD-U.

Key words: RPD-U, loading position, abutment tooth movement, denture base movement.

Introduction

Removable partial dentures (RPDs) are considered for rehabilitation of partially edentulous dental arch, restoring efficient function ensuring patient’s comfort with long term maintenance and stability. For patients with unilateral edentulism in molar region, RPD with a unilaterally designed framework (RPD-U) claimed to be more comfortable during mastication and speech, and more profound effect is anticipated on patients’ acceptance due to its relative simplicity.\(^1\) However, clinical use of the RPD-U is criticized owing to the poor retention and stability compared with the RPD with bilaterally designed framework (RPD-B).\(^2,3\) Poor denture stability may result in impingement of underlying tissues, or injury to residual alveolar ridges, and trauma to the periodontal support of abutment teeth. Residual ridge resorption and increased abutment teeth mobility may also follow as long term effects.

In relation to the designs of the denture framework such as direct retainer assemblies,\(^4,9\) indirect retainers\(^10\) and major connector\(^11\) are thought to improve the stability of the abutment teeth and denture base. Other researches suggest that proper impression tech-
niques\textsuperscript{12} and denture base adaptations\textsuperscript{13} enhance the mucosal supports minimizing the denture movements. In addition, occlusal considerations such as arrangement of artificial teeth\textsuperscript{14} and occlusal cusp inclinations\textsuperscript{15} are known to influence the movements of the abutment teeth and denture base. In designing the direct retainers, especially in positioning the occlusal rests, attention is paid to prevent the movements of the abutment teeth and the denture base. And it was considered that the mesiocclusal rest provides better biomechanical behavior than distocclusal rest.\textsuperscript{4,6,8,9} Further, it has been well documented that placing many indirect retainers\textsuperscript{10} which are well connected with the rigid major connector,\textsuperscript{11} are useful in obtaining sufficient retention and stability for smooth function of RPD. On the other hand, many studies have highlighted the importance of designing simple frameworks\textsuperscript{16,17} because complex designs could potentially yield negative effects on oral hygiene,\textsuperscript{17,18} esthetics and comfort of the patients.

Ohyama\textsuperscript{19} constructed a novel design for RPD-U for molar region, which consisted of mesiocclusal rest with a back-action clasp on second premolar as direct retainer and an embrasure-hook between the canine and the first premolar as indirect retainers. This novel unilateral design, with an embrasure-hook and a rigid lingual bracing arm that located under the survey line, strongly resisted the vertical dislodgement and instability of the denture.\textsuperscript{19} Its dynamic retentive forces have been determined experimentally,\textsuperscript{20} and considered to be sufficient for ordinary clinical requirements. Mizuuchi and colleagues\textsuperscript{9} investigated the movements of abutment tooth and denture base with the back-action clasp type and the akers clasp type, and demonstrated that the presence of back-action clasp type exhibited lower degrees of movements of the abutment tooth and denture base. They also suggested that the positional loading of the denture base would be a significant factor in influencing the movements of the abutment tooth and denture base.

Therefore, it could be hypothesized that by controlling the loading positions the movements of the abutment tooth and denture base of the RPD-U could be minimized to a degree equal to that of RPD-B. Thus the present study was aimed to explore the effects of different loading positions on the movements of the abutment tooth and denture base of RPD-U designed to restoring mandibular unilateral molars. The movements of abutment tooth and denture base were determined and compared between the RPD-U and the RPD-B under simulated clinical settings.

Materials and Methods

Experimental Mandibular Model

An acrylic resin model (Devcon ET, I.T.W. Industries, Co., Japan) of a mandible without left molars was constructed from an anatomically corrected model (E50-518, Nissin Dental Products Inc., Japan). The five abutment teeth, four premolars and left canine, were cast in gold palladium alloy (Castwell M.C. 12% Gold. GC Co., Japan). Roots of the abutment teeth were coated with an approximately 1-mm thick layer of silicone (Exafine regular, GC Co., Japan) to simulate the periodontal ligament. Silicone layers (Fit checker, GC Co., Japan) with uniform thickness 4 mm and 2 mm were used to fabricate soft tissue replica at the distal extension region and lingual gingival area near the dentate region, respectively.

Experimental denture frameworks

Ten RPD frameworks, consisting of five frameworks each for the two designs, RPD-U and RPD-B (Fig. 1), were fabricated with platinum gold alloy (Type IV, Dentsply-Sankin K. K., Japan). A back-action clasp was used as a direct retainer for both designs. The path of denture placement of the RPD-U was determined using a dental surveyor. During the surveying, the cast was tilted to the edentulous side ensuring that the both lingual bracing arm and buccal retentive arm of the clasp were in the undercut area resulted against the vertical direction of the occlusal plane.\textsuperscript{19} The RPD-B was designed on the teeth relative horizontal survey. As an indirect retainer in the unilateral design, an embrasure-hook was employed between the canine and the first premolar. Bilateral design used a double-akers clasp on the right premolars and a mesiocclusal rest on the left first premolar as indirect retainers. The same portions of the two framework designs were attempted.

![Fig. 1. Schematic illustrations of the experimental denture frameworks with loading platform. 1-1: Removable partial denture with unilaterally designed framework (RPD-U), and 1-2: Removable partial denture with bilaterally designed framework (RPD-B). Notice that a mesiocclusal rest back-action clasp was used as a direct retainer with two denture designs.](image-url)
to control in an identical dimension. Acrylic resin dentures were fabricated with auto-polymerizing resin (Repairsin, GC Co., Japan) and extended to one half of the retromolar pads and full functional depth of the buccal and lingual sulci. An interchangeable metal loading platform was placed on the denture base corresponding to the occlusal surface, on which twelve loading positions were established. Four central loading positions (C1, C2, C3 and C4) were determined mesiodistally on the residual ridge crest at a 5-mm interval from the distal marginal ridge of the primary abutment. Buccal (B1, B2, B3 and B4) and lingual loading positions (L1, L2, L3 and L4) were offset 3.5 mm buccally and lingually, respectively, from central loading positions (C1, C2, C3 and C4).

Measurements

Fig. 2 illustrates the universal testing machine (AGS-H, Shimadzu Co., Ltd., Japan) that was used to apply a load to the loading platform with a crosshead speed of 0.5 mm/min. A vertical load of 30N was used to simulate the chewing force. Seven specially designed steel plates (a1, b1, c1, e1, e2, f1 and f2), each of which was equipped with four strain gauges (KFG-5-120-C1-11, Kyowa Electronic Instruments Co., Ltd., Japan), were used as the measuring devices. Four strain gauges, two gauges attached on either surface of a steel plate, were connected to a Wheatstone electronic bridge circuit to compensate for any ambient temperature fluctuation. Each steel plate was calibrated with 10 µm interval using a universal testing machine (AGS-H, Shimadzu Co., Ltd., Japan) before and after making the measurements. The linearity error of these steel plates in each direction was less than 0.5% for a range of ±500 µm. To measure the movement of the abutment tooth, a metal rod with two beads (measuring points E and F) was vertically attached to the occlusal center of the abutment tooth. In relation to the denture base, three measuring points (A, B and C) were placed on a loading platform attached to the denture base. Throughout the measuring process, the three steel plates (a1, b1, and c1) with strain gauges were in contact with the points A, B and C in vertical direction, and the four steel plates (e1, e2, f1 and f2) were in contact with the measuring points E and F in mesiodistal and buccolingual directions (Fig. 2). As the testing load was applied, signals from the strain gauges of each steel plate were amplified (MCC-8A, Kyowa Electronic Instruments Co., Ltd., Japan), transmitted, and recorded simultaneously with dynamic loads by Chart software (Chart for Windows V4.1.2, ADInstruments Pty., Ltd., Australia) following A/D conversion (PowerLab/16sp, ADInstruments Pty., Ltd., Australia). From the excursions of each measuring point, the inclinations of the denture base in the anteroposterior and buccolingual directions, and the displacements of the occlusal center of abutment tooth in the mesiodistal and buccolingual directions were calculated (Fig. 3). Each measurement was repeated five times for each loading position under the same conditions, allowing an interval of 3 minutes for complete recovery of the silicone material.

Statistical Analysis

The Friedman’s nonparametric analysis of variance was performed to determine significant differences among loading positions across mesiodistal and buccolingual directions with each denture design. The Wilcoxon signed-rank test with a Bonferroni correction was used for multiple comparisons between loading positions across both directions. The Mann-Whitney U test was used to determine the difference between the two denture designs at each loading position. Statistical analysis was performed using SPSS Version 10.0 (Japanese) for Windows, and statistical significance was established at P<0.01.
Results

1. Anteroposterior denture base inclinations and mesiodistal abutment tooth displacements

Shifting of loading positions mesiodistally

During the shifting of loading positions from C1 to C4, the Friedman’s test demonstrated that there were significant differences (P < 0.01) in anteroposterior inclinations of the denture base between the different loading positions in both designs. Especially during the loading on C4, denture bases exhibited significantly greater (P < 0.01) posterior inclinations than during the loading on the more mesial positions in both RPD designs (Wilcoxon signed-rank test) and the RPD-U resulted in significantly greater (P < 0.01) posterior inclinations of denture base than the RPD-B (Mann-Whitney U test) (Fig. 4-1).

In relation to the mesiodistal displacement of the abutment tooth during the loading on the central loading positions (C1, C2, C3, and C4), the Friedman’s test demonstrated that there were significant differences (P < 0.01) among the loading positions in RPD-U. During the loading on C4, mesial displacement of the abutment tooth was significantly greater (P < 0.01) than that during the loading on the more mesial positions (C1, C2, and C3) (Wilcoxon signed-rank test). Moreover, the RPD-U resulted in significantly greater (P < 0.01) mesial displacement of the abutment tooth than the RPD-B (Mann-Whitney U test). During the loading on C1, C2, and C3, significant differences were not found (P > 0.01) either between the two denture designs (Mann-Whitney U test) or among these loading positions (Wilcoxon signed-rank test) (Fig. 4-2).

Similar responses of the anteroposterior inclinations of the denture base and the mesiodistal displacements of the abutment tooth during the loading on central positions were also observed during the loading on buccal (B1, B2, B3 and B4) and lingual (L1, L2, L3 and L4) positions (Fig. 5-1, 5-2).

Shifting of loading positions buccolingually

During the shifting of loading positions from buccal to lingual direction, the anteroposterior inclinations of the denture base tended to increase in both designs. However, significant differences were not found (P > 0.01) among the loading positions across the buccolingual direction within each portion (portion 1 (B1, C1 and L1), portion 2 (B2, C2 and L2), portion 3 (B3, C3 and L3) and portion 4 (B4, C4 and L4)) (Friedman’s test). The RPD-U resulted in significantly greater (P < 0.01) posterior inclinations of the denture base than the RPD-B in portions 3 and 4 (Mann-Whitney U test) (Fig. 5-1).

During the shifting of loading positions from buccal to lingual direction, mesiodistal displacements of the abutment tooth were not significantly different (P > 0.01) either between the two denture designs (Mann-Whitney U test) or among the loading positions across the buccolingual direction (Friedman’s test) within portions 1, 2, and 3. In portion 4, the RPD-U resulted in significantly greater (P < 0.01) mesial dis-
placements of the abutment tooth than the RPD-B (Mann-Whitney U test) (Fig. 5-2).

2. Buccolingual denture base inclinations and abutment displacements

In relation to the buccolingual denture base inclinations and abutment tooth displacements, Friedman’s test demonstrated significant differences (P < 0.01) among the loading positions across both buccolingual and mesiodistal directions within each portion (portion 1 (B1, C1 and L1), portion 2 (B2, C2 and L2), portion 3 (B3, C3 and L3) and portion 4 (B4, C4 and L4)) and each loading position (buccal (B1, B2, B3 and B4), central (C1, C2, C3 and C4) and lingual (L1, L2, L3 and L4) loading positions). The buccolingual denture base inclinations and abutment tooth displacements were significantly greater (P < 0.01) for loading on two of the three most distal positions (C4 and L4) than the mesial positions to C4 and L4. The opposite result was observed upon loading on B4 (Wilcoxon signed-rank test) (Fig.6-1, 6-2 and Table).

Shifting of loading positions mesiodistally

During the shifting of loading positions from mesial to distal direction, the buccal inclinations of the both design denture bases tended to decrease, with no significant difference (P > 0.01) between the two designs during the loading on buccal positions (B1, B2 and B3) (Mann-Whitney U test). During the loading on central positions (C1, C2, and C3), both denture base inclinations changed from buccal inclination to lingual inclination, and significant differences were not found (P > 0.01) between two designs (Mann-Whitney U test). During the loading on lingual positions (L1, L2 and L3), the lingual inclinations of the both denture bases tended to increase, the RPD-U showing significantly greater (P < 0.01) inclinations than the RPD-B (Mann-Whitney U test) (Fig. 6-1 and Table).

During the shifting of loading positions from mesial to distal direction, the buccal displacements of the abut-
ment tooth tended to decrease with the RPD-B, while constant buccal displacements were exhibited by the RPD-U during the loading on the buccal positions (B1, B2 and B3). The RPD-U resulted in significantly greater (P < 0.01) buccal displacements than the RPD-B (Mann-Whitney U test). During the loading on the central positions (C1, C2, and C3), although the buccolingual displacements of the abutment tooth were significantly different (P < 0.01) between the two designs (Mann-Whitney U test), the degrees of displacement were quite similar. During the loading on the lingual positions (L1, L2 and L3), the lingual displacements of the abutment tooth were increased in both designs, and the RPD-U resulted in significantly greater (P < 0.01) lingual displacements than the RPD-B (Mann-Whitney U test) (Fig. 6-2 and Table).

Shifting of loading positions buccolingually

During the shifting of loading positions from B1 to L1 in portion 1, the denture base inclinations changed from buccal inclination to lingual inclination (P < 0.01) in both designs (Friedman’s test). During the loading on B1 and L1 positions, the degrees of buccolingual inclination of the denture base were significantly higher (P < 0.01) than that during the loading on C1 position in both designs (Wilcoxon signed-rank test). During the loading on B1 and C1 positions, the buccolingual inclinations of the denture base were not significantly different (P > 0.01) between the two designs (Mann-Whitney U test). During the loading on L1 position, the RPD-U resulted in significantly greater (P < 0.01) lingual inclinations than the RPD-B (Mann-Whitney U test). The same results in the buccolingual inclinations of denture base were also observed in both potions 2 and 3 (Fig. 6-1 and Table).

During the shifting of loading positions from B1 to L1 in portion 1, the abutment tooth displacements changed from buccal displacement to lingual displacement (P < 0.01) in both RPD designs (Friedman’s test). During the loading on the B1 and L1 posi-
tions, the degrees of buccolingual displacement of the abutment tooth were significantly higher (P < 0.01) than that during the loading on the C1 position in both designs (Wilcoxon signed-rank test). During the loading on the C1 position, although the buccolingual displacements of the abutment tooth were significantly different (P < 0.01) between the two designs (Mann-Whitney U test), the degrees of displacement were quite similar. During the loading on the B1 and L1 positions, the RPD-U resulted in significantly greater (P < 0.01) buccolingual displacements than the RPD-B (Mann-Whitney U test). The same results in the buccolingual displacements of the abutment tooth were also observed in both potions 2 and 3 (Fig. 6-2 and Table).

Discussion

In unilateral distal extension edentulous arch, it is generally accepted that the RPD-B, with the major connector joining the edentulous side and contra-lateral side with retentive and stabilizing components, is an effective way to obtain sufficient retention and stability of the denture base. Although the relatively smaller RPD-U is preferred by patients, it is still being criticized for having impaired retention and stability compared to the RPD-B. Thus, the movements of the abutment tooth and the denture base of the RPD-U were compared with the RPD-B from the viewpoint of the loading position to reveal some guidelines for using the RPD-U in mandibular unilateral molars edentulous arch.

The two structures that support a distal extension RPD, i.e. the periodontal ligament and the mucous membrane, exhibit viscoelastic properties, and for both, load-displacement curves take place in two distinct phases. However, as the present study estimated the forces transmitted to the abutment tooth and denture-bearing ridge by measuring its movements, it is necessary to simulate the initial linear phase of the load-displacement curves of these structures. Therefore, in the simulation model, 1-mm thick exafine regular type silicone materials represented the periodontal ligament, and 4-mm thick fit checker silicone material represented the mucous membrane, as these exhibit an identical ratio between the load-displacement curves of these two oral tissues. The findings of the preset study confirmed a high linear relationship in each direction for load-displacement curves of these two elastic materials as shown in Fig. 7.

Load was applied on each loading position simulating specific occlusal contact during the mastication. In previous studies an equal load to maximum occlusal force has been used as the test load. However, in normal chewing such high occlusal forces are seldom detected. In the present study, a 30N vertical load, which corresponds with an average chewing force required for most food types, was selected. Moreover, each loading position, established on loading platform, was determined to represent the respective anatomic occlusal positions of mandibular first and second molars as shown in Fig. 1.

According to the previous studies, the movements of the abutment tooth and denture base were significantly influenced by positional loadings. In the present study, when the vertical forces were applied on the B4, C4 and L4, the posterior inclinations of the denture base and mesial displacements of the abutment tooth were significantly greater than that during the loading on the more mesial loading positions in RPD-U. Vertical displacements (lifting and depression) of the anterior and posterior denture base during the loading on the central positions (C1, C2, C3 and C4) are compared in detail in Fig. 8 (This data is not mentioned under results). A considerably increased depression of posterior denture base and a lifting movement of the anterior denture base were observed on the C4 position. Apparently on this loading position, it was impos-
sible to maintain the prosthesis despite having sufficient retention for ordinary clinical requirements. In addition, the anterior-downward movement of the denture base resulting from the dislodgement of the retainers, contributed significantly to the greater mesial abutment tooth displacements. It is predicted that, higher the retention given to prevent these movements, the greater the degree of resulting unwanted lifting forces to abutment tooth, even in the RPD-B. On the other hand, during the loading on the C1, C2, and C3 positions, both anterior and posterior regions of the denture base depressed with an anteroposterior inclination. The differences of the depression of the posterior denture base between the two denture designs were significant but rather small within 40 μm, that is a load like less than 1N, probably no clinical significance. Furthermore, the observation that the mesiodistal displacements of abutment tooth were minimum with both designs can presumably be explained as an efficiency of mesiobuccal rest. These results suggest that ending the denture teeth at the mesial cusp of the second molar of the RPD-U would minimize the anteroposterior inclinations of the denture base and mesiodistal displacements of the abutment tooth to a degree equal to that of RPD-B.

Moreover, our results suggest that the anteroposterior inclinations of denture base and mesiodistal displacements of the abutment tooth were not significantly influenced by shifting the loading positions on buccolingual direction.

During the loading on three most distal positions (B4, C4 and L4), the anteroposterior and mesiodistal movements of the denture base and the abutment tooth were considerable and resulted in frequent dislodge-ment of the prosthesis. Hence, the buccolingual movements of denture base and abutment tooth movements on these loading positions were not analyzed with those on more mesial positions.

The abutment tooth and denture base exhibited buccal displacement and inclination during the loading on buccal positions, lingual displacement and inclination during the loading on lingual positions in both RPD designs. These results are congruous with those reported by Browning and colleagues. The results during the loading on buccal positions (B1, B2 and B3) showed that buccal inclinations of denture base were equal between two designs, whereas the abutment tooth of the RPD-U exhibited more buccal displacements than that of the RPD-B. Further additional analysis revealed that, the buccal displacements of the denture base of the RPD-U were greater than that of the RPD-B (This data is not mentioned under results). It is possible that the greater buccal displacements of the abutment tooth of the RPD-U were resulted probably by the higher buccal displacements of the denture base due to lack of indirect retainers on the contra-lateral side. For the same reason, the RPD-U demonstrated more lingual movements of the denture base and abutment tooth than the RPD-B during the loading on lingual positions (L1, L2 and L3).

By tilting the cast to the edentulous side during the surveying, the survey line on the lingual surface of the abutment tooth is lowered. Consequently, the lingual bracing arm of the RPD-U in a lowered position promises reasonable reciprocal effect of the buccal retention arm, and may stabilize the abutment tooth and denture base. The result that the magnitudes of buccolingual inclinations and displacements of denture base and the abutment tooth of the RPD-U were similar to that of the RPD-B during the loading on central positions (C1, C2, and C3) could be explained by reasonable reciprocal effect of the RPD-U. Moreover, the buccolingual movements of the abutment tooth and denture base during the loading on central positions (C1, C2, and C3) were significantly lower than during the loading on buccal (B1, B2 and B3) and lingual (L1, L2 and L3) positions. These results suggest that by positioning the occlusal contacts over the ridge crest, the movements of the abutment tooth and denture base of the RPD-U could be minimized.
explained by the morphology of the mandibular ridge supporting the denture base; the buccolingual inclination of buccal residual ridge flattens toward the distal, and the movements of the denture are prevented. This suggests that the effects of the morphology of the mandibular residual ridge on the movements of the abutment tooth and denture base should be further investigated.

Our starting hypothesis that by controlling the loading positions the movements of the abutment teeth and denture base of the RPD-U could be minimized to a degree equal to that of RPD-B has been demonstrated to be valid in this study. Although this in vitro study can not identically reproduce the real clinical situation, the results indicate that in mandibular unilateral molars edentulous patients, by ending the denture teeth at the mesial cusp of second molar and positioning the occlusal contacts over the ridge crest the movements of the abutment tooth and denture base of the RPD-U could be minimized comparably to the level of the RPD-B. From another aspect, it is suggested that not only the occlusal contacts position but also the type of denture design, such as using the RPD-B or RPD-U, should be taken into consideration when the denture teeth have to be placed away buccally or lingually from the ridge crest due to the position of the opposing teeth.

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References