Influence of retainer and major connector designs of removable partial dentures on the stabilization of mobile teeth: A preliminary study

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The purpose of this study was to investigate the influence of retainers and major connector designs on the stabilization of remaining mobile teeth using removable partial dentures (RPDs). We prepared experimental RPDs with several retainer designs and major connectors for lower Kennedy class I models. The simulated RPD insertion and removal test was conducted and retentive force and mobility of mobile remaining teeth with and without RPD placement were measured throughout a simulation test. Regardless of reduction of retentive force, the placement of RPDs using cast clasps and/or lingual plates resulted in reduced mobility of the remaining teeth than use of wrought wire clasps and/or lingual bars. The results suggested that cast clasps and lingual plates are effective for the stabilization of mobile, remaining teeth. Additionally, the stabilizing effect of RPD on abutment teeth was not diminished, despite decreases in retentive force.

Keywords: Removable partial denture, Tooth mobility, Mobile teeth, Stabilization

INTRODUCTION

In patients who lose their teeth due to periodontal disease, periodontal supporting tissues for the remaining teeth are often weakened and at risk, even after periodontal treatment. Supportive periodontal therapy (SPT) and appropriate occlusal rehabilitation are essential for the prevention of further tooth loss in these patients. Compared to bridges and implants, removable partial dentures (RPDs) can recover oral function without excessive cutting or surgical treatment/removal of remaining teeth and can be widely applied in patients who have general health problems or who are resistant to invasion of the remaining tissue. In addition, RPDs can easily be modified following future tooth loss so that the patients can maintain oral function.

It has been reported that mobile teeth that are weakened by periodontal disease are at higher risk of loss, even when SPT is applied by periodontists. Prosthodontists sometimes attempt to protect weakened mobile teeth by stabilizing them against one another using prostheses. As has been referred to in reviews and textbooks, RPDs can be carefully designed to stabilize the remaining teeth indirectly. However, this “stabilizing effect” of RPDs, which means acting as an occlusal splint, has only been reported in terms of applying guiding planes or design specifics and has not yet been verified scientifically with common components of RPDs, such as proximal plates, clasps (either cast or wrought wire clasps), and connectors. Moreover, it is generally believed that the degree of tooth movement while the RPD is in place varies based on the RPD design.

Regarding changes to these devices with use, several in vitro studies have reported that the retentive force of a clasp was reduced by simulated RPD insertion and removal testing. Other in vivo studies have reported that the RPDs with clasps were associated with slight but significant increases in gingival recession 5 years after RPD placement. This indicates that destabilization or changes to RPDs themselves that might disadvantage remaining teeth often occur with long-term RPD use. Furthermore, both in vitro and in vivo studies have assessed the displacement of abutment teeth. These studies have collectively suggested that rigid retainers and major connectors may prevent the displacement of abutment teeth and of the RPD itself. However, changes to the efficacy of RPDs of various designs with long-term use have not been evaluated as of yet. Further, the existing research has focused on changes only to healthy abutment teeth, rather than those weakened by periodontal disease, leaving a significant gap in the existing literature.

To protect mobile teeth using RPDs with retainers and major connectors, a better understanding of design requirements necessary for appropriate stabilization of remaining mobile teeth is required. Valid designs of RPD to protect mobile teeth must be tested further to ensure that they can be practically applied to the oral cavity.

The present study was performed to clarify the effectiveness of RPD retainers and major connectors on the stabilization of remaining mobile teeth in dental patients as a preliminary study for follow-up clinical studies in the oral cavity. We created a simulated mobile teeth model (mandibular Kennedy Class I) with an artificial periodontal ligament and artificial mucosa according to previous studies, as well as experimental RPDs including several retainers and major connectors.
with differing designs. We then evaluated the stabilizing effect of these various RPD designs using measurements of mobility in the remaining teeth with and without each experimental RPD during a simulated RPD insertion and removal test. The purpose of this study was to investigate the influence of two major RPD components—retainers and major connectors—of various designs on the stabilization of mobile remaining teeth. We expected that the placement of an RPD using a cast clasp and/or a lingual plate for a mandibular Kennedy Class I dental arch would reduce the mobility of remaining teeth, a stabilizing effect that would be lower with a smaller retentive force.

MATERIALS AND METHODS

Reference models and experimental RPD
Two different commercially-available mandibular models for Kennedy class I dentures (E50-522 and E50-550, Nissin Dental Products, Kyoto, Japan) were used as reference models. The reference models were labeled as A and B. Missing and abutment teeth in each model are shown in Table 1. Each abutment tooth was covered with surveyed, complete-coverage crowns casted in Co-Cr alloy (Cobaltan, Shofu, Kyoto, Japan). The preparation for each RPD was incorporated into the surveyed crowns. The insertion and removal paths were directionally perpendicular to the occlusal plane. Working casts used to fabricate the experimental RPDs were duplicated from reference models with surveyed crowns on the abutment teeth. The designs of the experimental RPDs are shown in Figs. 1 and 2 and labeled as A1 to A5 and B1 to B5 for models A and B, respectively. In regard to clasp design, A1, B1, and B2 were designed with wrought wire clasps (B1 and B2 were designed with and without an occlusal rest, respectively), whereas the other RPDs were designed with cast clasps. In regard to major connector design, A4, A5, and B5 were designed with lingual plates, whereas the other RPDs were designed with lingual bars. The experimental RPDs were fabricated with a Co-Cr cast framework and heat-polymerizing denture base resin by an experienced dental technician.

Measurement of retentive force
Simulation models for RPD insertion and removal testing and measurement of retentive force were constructed using epoxy resin (Crystal Resin, Nissin Resin, Kanagawa, Japan) and duplicated from a reference model (Fig. 3-A). The surveyed crowns were transferred from reference models and cemented onto abutment teeth.

Table 1 Reference model characteristics

| Missing teeth | Abutment teeth | Model name  |
|---------------|---------------|-------------|
| #34, 35, 36, 37, 44, 46, 47 | #33, 43 | model A |
| #36, 37, 46, 47 | #35, 45 | model B |

Fig. 1 Designs of experimental removable partial dentures in model A.
The design of major connectors was standardized (lingual bar) among A1, A2 and A3. The design of retainers was standardized (cast Akers clasp) among A3, A4 and A5.
in the simulation models. The surface of the denture bearing area was replaced by a 2-mm-thick layer of a silicone impression material (Examixfine regular type, GC, Tokyo, Japan), which served as artificial mucosa. The elastic modulus of this silicone impression material was reported to be in the same range as that of normal human oral mucosa.

The force (N) required to remove the RPD from the simulation model was defined as the retentive force, and it was measured using a universal testing machine (Autograph AGS-H, Shimadzu, Kyoto, Japan) with a crosshead speed of 8 mm/s. After measuring the retentive force, the simulation models were mounted to a desktop robot (TTA-A3G, IAI, Shizuoka, Japan) such that the path of RPD insertion and removal was parallel to the abutment crown’s guiding plane (Figs. 3-B, C). Simulated RPD insertion and removal testing was conducted with the following cycling sequences:
250, 500, 1,000, 2,500, and 5,000 times. Previous studies indicated that cycling sequences ranging from 5,000–7,000 times simulated 5-year-long RPDs usage\(^{14,22,23}\). A desktop robot with a crosshead speed of 8 mm/s was used for all simulations. After each cycle, the retention force was measured five times.

**Measurement of remaining tooth mobility**

To measure the mobility of the remaining teeth, reference models were modified to prepare mobile teeth models using the following procedures: First, artificial teeth were constructed of epoxy resin (Crystal Resin, Nissin Resin) duplicated from abutment teeth covered with surveyed crowns. Next, the abutment teeth on the reference models were replaced by the epoxy resin artificial teeth. We prepared one mobile teeth model for each of A and B. The roots of all remaining teeth, including the epoxy resin teeth, were coated in 1-mm-thick silicone material (Examixfine regular type, GC) to simulate the periodontal ligaments (Figs. 4-A, B). Tooth mobility was measured using an electronic tooth mobility measuring device (Periotest M, Gulden-Medizintechnik, Bensheim, Germany, Figs. 4-C, D). The Periotest M is an instrument designed to measure the damping characteristics of periodontal ligaments and evaluate their mobility. This device is comprised of a handpiece containing a metal “slug” that accelerates toward the tooth 16 times in 4 s. The results are represented as Periotest values (PTVs), ranging from −8 to 50, and determined by the contact time between the device and tooth surface. The mobility of all remaining teeth in the mobile teeth models was adjusted such that the PTVs for all teeth ranged from 20 to 29 (Table 2).

In preparing the mobile teeth models, we adjusted the degree of tooth mobility by shortening the height of the artificial periodontal ligament toward the apex of the root, therefore simulating a reduction to the bone which supports teeth in the oral cavity\(^{24,25}\). Furthermore, the process used to prepare artificial periodontal ligaments in the present study was found to provide sufficiently high accuracy via the simulation experiments conducted here. According to our pilot testing during the planning phase of this study, we further found that damping direction (buccal or lingual) had no influence on PTVs with RPD placement in relation to the remaining teeth, including teeth in contact with the lingual plate. Given this, we selected the buccal surface of the remaining teeth as a damping surface for measurements in the oral cavity.

After adjustment of mobility degree, the mobility of all remaining teeth was measured with the Periotest M. Five measurements were performed at each remaining tooth, both with and without RPD. After each simulation cycle, the mobility of the remaining teeth with and without RPD placement was measured. Before each measurement, the artificial periodontal ligaments were replaced with new silicone materials and tooth mobility without RPDs was confirmed and modified such that

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**Table 2**  Miller’s scores of mobility and Periotest values

| Miller’s classification                                                                 | Score of mobility | Periotest value |
|----------------------------------------------------------------------------------------|-------------------|-----------------|
| No movement distinguishable                                                             | 0                 | −8 to 9         |
| First distinguishable sign of movement                                                  | 1                 | 10 to 19        |
| Tooth deviates within 1 mm of its normal position                                       | 2                 | 20 to 29        |
| Mobility is easily noticeable and the tooth moves>1 mm in any direction or can be rotated in its socket | 3                 | 30 to 50        |
the PTVs for all teeth ranged from 20 to 29. Adjustment of these models and subsequent data collection were performed by the same examiner (T.N.).

**Scanning electron microscopy (SEM)**

For lingual A4 (Co-Cr) and A5 (polymethyl methacrylate; PMMA) plates, the internal surfaces were assessed for evidence of material wear via SEM (Hitachi S-4500N, Hitachi, Tokyo, Japan). After 5,000 cycling sequences, two areas of the internal surface were selected for assessment using a fit checker (FIT CHECKER, GC, Tokyo, Japan) and extracted as specimens (sections used for SEM evaluation) from each lingual plate. These two areas consisted of (1) the “contacted area,” on which there was no fit checker (this represented the contact area with remaining teeth throughout the simulated RPD insertion and removal test) and (2) the “non-contacted area,” on which a thick fit checker remained (this represented the area that was not in contact with the remaining teeth and did not change from baseline throughout the simulation test) (Fig. 5). Ideally, SEM evaluations should be conducted both before and after simulated insertion and removal testing. However, it was necessary to cut specimens out of the experimental RPDs for SEM evaluations. In the present study, we cut two specimens (3×7 mm) out from two different areas of the lingual plates (contacted and non-contacted areas) for SEM evaluation only after simulated insertion and removal testing. Specimens were finally mounted on aluminum stubs and sputter coated with gold in an ion sputter coater (Quick Auto Coater sc-701AT; Sanyu Electron, Tokyo, Japan). Each specimen was attached to the specimen stub, and it was observed at an accelerating voltage of 15 kV, and 200 times magnification.

**Statistical analyses**

To evaluate the stabilizing effect of the experimental RPDs on the remaining teeth, a decreasing PTV ratio (with RPD placement to without RPD placement) was defined as the stabilizing ratio (SR). For each abutment tooth, the SR (%) was calculated using the following formula:

\[
SR(\%) = \left( \frac{PTV \text{ w/o RPD} - PTV \text{ w/ RPD}}{PTV \text{ w/o RPD}} \right) \times 100
\]

A higher SR indicated that the RPD better stabilized the tooth. Those abutment teeth and central incisors

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**Fig. 5** Magnified photograph of the internal surfaces of lingual plate. The squares represent the areas visualized via SEM. The contact area (a) was in contact with the cingulum of the central incisor and the non-contact area (b) covered the interdental papilla.

**Fig. 6** The retentive force behavior for each configuration of the model A design during the simulated denture insertion and removal test. In all designs except A1, the retentive force after 5,000 cycles was significantly lower than it was at baseline (p<0.01).

**Fig. 7** The retentive force behavior for each design of model B during the simulated denture insertion and removal test. In all designs, the retentive force after 5,000 cycles was significantly lower than it was at baseline (p<0.01).
to which no retainer was applied were used as SR evaluation targets. SR data were statistically analyzed after summing results from both sides of the mouth (n=10). The Kolmogorov-Smirnov test was used for normality analyses, and for those data which were not found to be normally distributed, non-parametric statistical analyses were conducted. The retentive force and SR after each cycle of simulated RPD insertion and removal was compared to a baseline using the Mann-Whitney’s U test and the Bonferroni correction. For each model, a comparison of SR among the five RPD designs was conducted at each measurement by using a Kruskal-Wallis’s test and pairwise comparison. All statistical analyses were performed using statistical analysis software (SPSS version 22.0, IBM, Armonk, NY, USA) and a p value <0.05 was considered to be significant.

Table 3 PTV and SR of the abutment tooth (canines) with use of RPD model A

| RPD design | Cycling sequence of simulated RPD insertion and removal |   |   |   |   |
|------------|--------------------------------------------------------|---|---|---|---|
|            | Baseline 250 500 1,000 2,500 5,000 | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) |
|            | PTV | SR | PTV | SR | PTV | SR | PTV | SR | PTV | SR | PTV | SR | PTV | SR | PTV | SR |
| A1 (w/o RPD) | 23.9 (2.5) | 75.7 (4.6) | 25.9 (1.5) | 73.7 (2.9) | 25.3 (3.6) | 72.2 (3.9) | 26.7 (1.3) | 74.0 (4.8) | 27.0 (1.7) | 72.1 (1.1) | 25.1 (0.6) | 72.6 (3.7) | 25.0 |
| A1 (w/ RPD) | 5.9 (1.6) | 4.6 (0.8) | 5.7 (1.7) | 4.7 (1.1) | 5.1 (1.7) | 4.7 (1.1) | 5.9 (1.7) | 4.7 (1.1) | 5.9 (1.7) | 4.7 (1.1) | 5.9 (1.7) | 4.7 (1.1) | 5.9 (1.7) | 4.7 (1.1) | 5.9 (1.7) | 4.7 (1.1) |
| A2 (w/o RPD) | 24.7 (0.6) | 86.9 (0.6) | 26.6 (0.9) | 87.0 (0.8) | 26.7 (0.7) | 87.2 (0.6) | 27.0 (0.6) | 87.4 (0.3) | 27.1 (0.1) | 87.3 (0.5) | 28.0 (0.2) | 87.9 (0.5) | 27.4 |
| A2 (w/ RPD) | 3.2 (0.1) | 89.1 (0.6) | 3.5 (0.2) | 90.8 (0.6) | 3.4 (0.1) | 92.4 (0.6) | 3.4 (0.1) | 91.8 (0.6) | 3.4 (0.1) | 92.4 (0.6) | 3.4 (0.1) | 91.8 (0.6) | 3.4 (0.1) | 92.4 (0.6) | 3.4 (0.1) | 91.8 (0.6) |
| A3 (w/o RPD) | 25.7 (1.2) | 91.2 (1.3) | 26.8 (1.3) | 91.8 (1.0) | 27.2 (1.3) | 92.4 (1.0) | 26.2 (1.3) | 91.8 (1.2) | 27.7 (1.2) | 92.4 (1.2) | 27.7 (1.2) | 91.8 (1.2) | 27.7 (1.2) | 92.4 (1.2) | 27.7 (1.2) | 91.8 (1.2) |
| A3 (w/ RPD) | 2.3 (0.3) | 92.5 (1.4) | 2.2 (0.3) | 92.4 (1.7) | 2.1 (0.2) | 92.3 (1.7) | 2.2 (0.2) | 92.4 (1.7) | 2.2 (0.2) | 92.4 (1.7) | 2.2 (0.2) | 92.4 (1.7) | 2.2 (0.2) | 92.4 (1.7) | 2.2 (0.2) | 92.4 (1.7) |
| A4 (w/o RPD) | 24.8 (0.4) | 91.0 (5.8) | 26.3 (0.7) | 88.5 (6.5) | 26.8 (0.3) | 87.7 (6.5) | 27.0 (0.6) | 90.0 (6.5) | 27.3 (0.3) | 90.0 (6.5) | 27.3 (0.3) | 90.0 (6.5) | 27.3 (0.3) | 90.0 (6.5) | 27.3 (0.3) | 90.0 (6.5) |
| A4 (w/ RPD) | 1.9 (1.4) | 92.0 (1.4) | 2.0 (1.7) | 92.4 (1.7) | 2.0 (1.7) | 92.3 (1.7) | 2.0 (1.7) | 92.4 (1.7) | 2.0 (1.7) | 92.4 (1.7) | 2.0 (1.7) | 92.4 (1.7) | 2.0 (1.7) | 92.4 (1.7) | 2.0 (1.7) | 92.4 (1.7) |
| A5 (w/o RPD) | 26.5 (1.1) | 91.0 (7.8) | 24.6 (0.5) | 88.5 (9.9) | 25.0 (0.4) | 87.7 (11.2) | 27.1 (0.5) | 90.0 (9.1) | 26.7 (0.9) | 88.9 (10.0) | 26.7 (0.9) | 88.9 (10.0) | 26.7 (0.9) | 88.9 (10.0) | 26.7 (0.9) | 88.9 (10.0) |
| A5 (w/ RPD) | 2.5 (2.2) | 92.5 (2.4) | 2.8 (2.4) | 92.4 (2.8) | 2.8 (2.4) | 92.3 (2.8) | 2.8 (2.4) | 92.4 (2.8) | 2.8 (2.4) | 92.4 (2.8) | 2.8 (2.4) | 92.4 (2.8) | 2.8 (2.4) | 92.4 (2.8) | 2.8 (2.4) | 92.4 (2.8) |

a: p value with Mann-Whitney’s U test and Bonferroni correction between the baseline and each cycle
b: p value with Kruskal-Wallis’s test among five RPD designs
RESULTS

Retentive force

Figures 6 and 7 show the retentive force of each design for the duration of the simulated RPD insertion and removal testing. At baseline, the retentive forces created by the RPDs with cast clasps were greater than those with wrought wire clasps. Regardless of statistical significance, the retentive force of each design for model A rapidly decreased between at baseline and after 250 cycle sequences. In contrast, the retentive force of each design for model B gradually decreased throughout 5,000 cycle sequences. In all designs except A1, the retentive forces after 5,000 cycle sequences were found to be significantly lower than those at baseline.

Table 4  PTV and SR of the abutment tooth (second premolars) with use of RPD model B

| RPD design | Cycling sequence of simulated RPD insertion and removal | Baseline | 250 | 500 | 1,000 | 2,500 | 5,000 |
|------------|--------------------------------------------------------|----------|-----|-----|-------|-------|-------|
|            | Mean (SD) | Mean (SD) | p value* | Mean (SD) | p value* | Mean (SD) | p value* | Mean (SD) | p value* | Mean (SD) | p value* |
| B1         |           |           |           |           |           |           |           |           |           |           |           |
| PTV (w/o RPD) | 25.8     | 25.8     | 26.1     | 26.8     | 26.6     | 26.7     |
| (w/RPD)    | (0.6)    | (0.4)    | (0.4)    | (0.3)    | (0.6)    | (0.3)    |
| PTV (w/o RPD) | 5.8     | 5.9      | 6.0      | 6.0      | 6.1      | 6.0      |
| (w/RPD)    | (1.0)    | (1.0)    | (0.9)    | (0.9)    | (0.9)    | (0.9)    |
| SR (%)     | 77.4     | 77.0     | 1        | 77.0     | 1        | 77.8     | 1        |
|           | (4.3)    | (4.0)    | (3.8)    | (3.7)    | (3.9)    | (3.4)    |
| B2         |           |           |           |           |           |           |           |           |           |           |           |
| PTV (w/o RPD) | 26.8     | 27.3     | 27.0     | 26.6     | 26.5     | 26.7     |
| (w/RPD)    | (0.6)    | (0.2)    | (0.2)    | (0.5)    | (1.0)    | (1.0)    |
| PTV (w/o RPD) | 5.2     | 5.3      | 5.4      | 5.6      | 5.6      | 5.6      |
| (w/RPD)    | (1.4)    | (1.4)    | (1.5)    | (1.6)    | (1.6)    | (1.6)    |
| SR (%)     | 80.7     | 80.7     | 1        | 79.9     | 1        | 78.8     | 1        |
|           | (4.6)    | (5.1)    | (5.6)    | (6.3)    | (6.8)    | (6.7)    |
| B3         |           |           |           |           |           |           |           |           |           |           |           |
| PTV (w/o RPD) | 26.7     | 25.5     | 25.5     | 26.2     | 26.0     | 26.9     |
| (w/RPD)    | (0.3)    | (0.7)    | (1.4)    | (0.7)    | (2.1)    | (0.7)    |
| PTV (w/o RPD) | 1.1     | 1.1      | 1.1      | 1.2      | 1.1      | 1.2      |
| (w/RPD)    | (0.6)    | (0.5)    | (0.6)    | (0.5)    | (0.5)    | (0.5)    |
| SR (%)     | 95.9     | 96.1     | 1        | 95.6     | 1        | 95.7     | 1        |
|           | (2.1)    | (1.9)    | (2.4)    | (2.0)    | (1.7)    | (1.9)    |
| B4         |           |           |           |           |           |           |           |           |           |           |           |
| PTV (w/o RPD) | 26.7     | 26.9     | 26.9     | 27.0     | 27.2     | 27.3     |
| (w/RPD)    | (1.0)    | (1.1)    | (0.7)    | (0.4)    | (0.5)    | (0.6)    |
| PTV (w/o RPD) | 1.9     | 2.1      | 2.1      | 2.0      | 2.1      | 2.1      |
| (w/RPD)    | (0.3)    | (0.3)    | (0.3)    | (0.2)    | (0.3)    | (0.3)    |
| SR (%)     | 92.7     | 92.0     | 1        | 92.3     | 1        | 92.5     | 1        |
|           | (0.9)    | (1.4)    | (1.2)    | (1.0)    | (1.0)    | (1.0)    |
| B5         |           |           |           |           |           |           |           |           |           |           |           |
| PTV (w/o RPD) | 27.0     | 26.0     | 25.3     | 26.4     | 26.7     | 26.5     |
| (w/RPD)    | (1.6)    | (1.0)    | (2.1)    | (1.3)    | (1.1)    | (1.8)    |
| PTV (w/o RPD) | 0.7     | 0.7      | 0.8      | 0.9      | 1.0      | 1.0      |
| (w/RPD)    | (1.5)    | (1.5)    | (1.7)    | (1.7)    | (1.8)    | (1.8)    |
| SR (%)     | 97.6     | 97.4     | 1        | 97.3     | 1        | 96.8     | 1        |
|           | (5.6)    | (5.8)    | (6.4)    | (6.3)    | (6.5)    | (6.4)    |
| p value*   | <0.001*  | <0.001*  | <0.001*  | <0.001*  | <0.001*  | <0.001*  |
| pairwise   | B1<B3, B4,  | B1<B3, B4,  | B1<B3, B4,  | B1<B3, B4,  | B1<B3, B4,  | B1<B3, B4,  |
| comparison | B5      | B5       | B5       | B5       | B5       | B5       |

a: p value with Mann-Whitney’s U test and Bonferroni correction between the baseline and each cycle
b: p value with Kruskal-Wallis’s test among five RPD designs
PTV and SR of the abutment teeth

The results of PTV and SR comparisons for the abutment teeth for each of the five RPD designs assessed here via simulated RPD insertion and removal testing in model A are shown in Tables 3 and 4, respectively. Regardless of cycle sequence, PTVs for RPDs placed with cast clasps and wrought wire clasps appeared to range from 0.7 to 3.5 and from 5.2 to 7.4, respectively. After each cycling sequence, the SRs of the RPDs placed with cast clasps were found to be significantly higher than those placed with wrought wire clasps. Regardless of RPD design, there was no significant change in SRs over the duration of the simulated test. In addition, even if the RPDs were designed with wrought wire clasps (as in A1, B1, and B2), the SRs with RPD placement ranged from 77 to 80%.

PTV and SR of the remaining teeth with no direct retainer

The results of a comparison of PTVs and SRs of the remaining teeth with no direct retainer (central incisors) applied in RPD model A and B are shown in Tables 3 and 4, respectively. Regardless of cycle sequence, PTVs for RPDs placed with cast clasps and wrought wire clasps appeared to range from 0.7 to 3.5 and from 5.2 to 7.4, respectively. After each cycling sequence, the SRs of the RPDs placed with cast clasps were found to be significantly higher than those placed with wrought wire clasps. Regardless of RPD design, there was no significant change in SRs over the duration of the simulated test. In addition, even if the RPDs were designed with wrought wire clasps (as in A1, B1, and B2), the SRs with RPD placement ranged from 77 to 80%.

Table 5  PTV and SR of the remaining tooth with no direct retainer (central incisors) applied in RPD model A

| RPD design | Cycles of simulated RPD insertion and removal | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) |
|------------|---------------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|            | Baseline                                          | 250       | 500       | 1,000     | 2,500     | 5,000     |          |
| A1         | PTV (w/o RPD)                                   | 23.4 (2.2) | 25.1 (1.8) | 25.3 (3.2) | 25.4 (3.3) | 24.4 (3.3) |          |
|            | PTV (w/ RPD)                                    | 22.1 (0.8) | 21.1 (0.8) | 21.1 (0.8) | 21.1 (0.8) | 21.1 (0.8) |          |
|            | SR (%)                                           | 6.2 (1.8)  | 7.6 (8.8)  | 7.6 (8.8)  | 7.6 (8.8)  | 7.6 (8.8)  |          |
| A2         | PTV (w/o RPD)                                   | 28.0 (1.0) | 26.0 (0.6) | 26.0 (0.6) | 26.0 (0.6) | 26.0 (0.6) |          |
|            | PTV (w/ RPD)                                    | 26.1 (0.8) | 24.9 (0.6) | 24.9 (0.6) | 24.9 (0.6) | 24.9 (0.6) |          |
|            | SR (%)                                           | 4.2 (2.0)  | 4.3 (2.0)  | 4.3 (2.0)  | 4.3 (2.0)  | 4.3 (2.0)  |          |
| A3         | PTV (w/o RPD)                                   | 25.9 (1.3) | 25.5 (1.0) | 25.5 (1.0) | 25.5 (1.0) | 25.5 (1.0) |          |
|            | PTV (w/ RPD)                                    | 26.8 (0.4) | 25.5 (0.4) | 25.5 (0.4) | 25.5 (0.4) | 25.5 (0.4) |          |
|            | SR (%)                                           | 1.3 (2.0)  | 3.9 (2.0)  | 3.9 (2.0)  | 3.9 (2.0)  | 3.9 (2.0)  |          |
| A4         | PTV (w/o RPD)                                   | 27.9 (0.5) | 28.1 (0.5) | 28.1 (0.5) | 28.1 (0.5) | 28.1 (0.5) |          |
|            | PTV (w/ RPD)                                    | 28.3 (0.6) | 28.3 (0.6) | 28.3 (0.6) | 28.3 (0.6) | 28.3 (0.6) |          |
|            | SR (%)                                           | 7.8 (2.0)  | 7.8 (2.0)  | 7.8 (2.0)  | 7.8 (2.0)  | 7.8 (2.0)  |          |
| A5         | PTV (w/o RPD)                                   | 22.4 (0.9) | 22.1 (0.9) | 22.1 (0.9) | 22.1 (0.9) | 22.1 (0.9) |          |
|            | PTV (w/ RPD)                                    | 27.7 (1.0) | 27.7 (1.0) | 27.7 (1.0) | 27.7 (1.0) | 27.7 (1.0) |          |
|            | SR (%)                                           | 81.9 (1.3) | 81.9 (1.3) | 81.9 (1.3) | 81.9 (1.3) | 81.9 (1.3) |          |

p value\*<0.001*<0.001*<0.001*<0.001*<0.001*
pairwise comparison A1, A3<A4, A5 A1, A2, A3 A1, A2, A3, A5 A1, A2, A3, A5 A1, A2, A3, A5 A2, A5

\*p value with Mann-Whitney’s U test and Bonferroni correction between the baseline and each cycle
b: p value with Kruskal-Wallis’s test among five RPD designs
remaining teeth applied with no direct retainer (central incisors) among the five designs assessed and over the duration simulated testing in model A and B are shown in Tables 5 and 6, respectively. Regardless of cycling sequences, there were few changes in PTVs of RPDs with lingual bars, while PTVs with RPD placement appeared to range from 3.7 to 11.6 in RPDs with lingual plates. After each cycling sequence, the SRs of the RPDs with lingual plates were significantly higher than those with lingual bars. After 5,000 cycling sequences, only the SR of A4 was significantly lower than at baseline.

**SEM**

SEM micrographs capturing the internal surface of the lingual plates are shown in Fig. 8. Of the lingual plate specimens constructed with Co-Cr alloy (A4), no apparent evidence of material wear was observed in either the contacted or non-contacted areas. In contrast, the lingual plates constructed with PMMA (A5) evidenced more material wear on the contacted area.

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**Table 6  PTV and SR of the remaining tooth with no direct retainer (central incisors) applied in RPD model B**

| RPD design | Baseline | 250 | 500 | 1,000 | 2,500 | 5,000 |
|------------|----------|-----|-----|-------|-------|-------|
|            | Mean (SD) | Mean (SD) | p value | Mean (SD) | p value | Mean (SD) | p value | Mean (SD) | p value | Mean (SD) | p value |
| B1         | PTV (w/o RPD) | 26.5 (0.4) | 25.8 (0.4) | 25.5 | 25.9 (0.6) | 25.5 |
|            | PTV (w/ RPD) | 25.6 (0.5) | 25.4 (0.4) | 25.2 | 25.2 | 25.8 |
|            | SR (%) | 3.5 (1.7) | 1.7 (1.2) | 1.2 (1.6) | 2.8 (3.0) | 0.945 |
| B2         | PTV (w/o RPD) | 24.6 (1.3) | 26.1 | 26.2 | 25.8 | 26.0 |
|            | PTV (w/ RPD) | 25.7 (1.0) | 26.3 | 26.2 | 26.0 | 26.4 |
|            | SR (%) | -4.8 (2.7) | -0.8 (1.6) | 0.0 <0.001* | -0.8 0.03* | -1.3 0.06 |
| B3         | PTV (w/o RPD) | 26.3 (1.2) | 26.0 | 26.2 | 26.0 | 24.8 |
|            | PTV (w/ RPD) | 26.4 (0.7) | 26.5 | 26.3 | 25.7 | 25.5 |
|            | SR (%) | -0.3 (2.1) | -2.1 0.945 | -0.4 1 | 1.2 1 | -3.1 0.945 |
| B4         | PTV (w/o RPD) | 26.0 (0.8) | 26.1 | 26.1 | 26.0 | 26.0 |
|            | PTV (w/ RPD) | 25.7 (0.8) | 25.6 | 25.6 | 25.6 | 25.9 |
|            | SR (%) | 0.8 (1.0) | 1.8 0.525 | 1.4 1 | 1.5 1 | 0.4 1 |
| B5         | PTV (w/o RPD) | 25.1 (1.0) | 26.8 | 25.6 | 25.4 | 24.7 |
|            | PTV (w/ RPD) | 11.2 (5.6) | 11.6 | 11.4 | 11.4 | 11.2 |
|            | SR (%) | 56.2 (20.9) | 58.5 0.945 | 57.3 0.945 | 56.4 1 | 56.6 1 | 55.9 1 |

**p value**

- <0.001*
- <0.001*
- <0.001*
- <0.001*
- <0.001*

**pairwise comparison**

- B2<B1, B1, B2, B3, B4
- B2, B3, B3<B5
- B2, B3, B5
- B2, B3, B4
- B4<B5
- B4<B5

**SEM**

- SEM micrographs capturing the internal surface of the lingual plates are shown in Fig. 8. Of the lingual plate specimens constructed with Co-Cr alloy (A4), no apparent evidence of material wear was observed in either the contacted or non-contacted areas. In contrast, the lingual plates constructed with PMMA (A5) evidenced more material wear on the contacted area.
than the non-contacted area.

**DISCUSSION**

For periodontally compromised patients with mobile teeth, clinicians have applied RPDs with special designs, such as the Swing-Lock RPD or the telescope denture. The Swing-Lock RPD consists of a hinged buccal bar, which provides retention and stabilization, attached to a conventional major connector. The construction of this type of RPD is relatively simple and inexpensive. However, this RPD has poor esthetic outcomes and produces an uncomfortable feeling on the lips. The telescope denture can stabilize remaining teeth rigidly like the fixed bridge and produces highly esthetic and functional results. However, this type of RPD needs aggressive intervention for the remaining teeth and high technical skills to be constructed. If RPDs with common components (such as proximal plates, clasps, and connectors) can act to protect the weakened mobile teeth, it will be beneficial for periodontally compromised patients.

This study focused on the stabilizing effect of RPD placement on remaining mobile teeth without functional loading, and further investigated the influences of RPD components on these effects, as evaluated by the retentive RPD force and tooth mobility with and without RPD placement over the duration of a simulated RPD insertion and removal test. The results revealed that retainer and major connector designs can have significant influences on the stabilizing effect of RPDs on remaining, mobile teeth.

The first significant result from the present study with regard to the influence of retainer design revealed that the placements of RPDs using cast clasps had a significantly greater stabilizing effect on the abutment teeth than use of wrought wire clasps. This finding indicates that directly applying a cast clasp to a retainer can stabilize mobile abutment teeth and increase their rigidity. The RPI clasp retainer applied in this study (A2) also had a proximal plate that contacted 3 mm of the guiding plane of the surveyed crown (known as Kratochvil's system). This type of RPI clasp retainer had a greater SR for the abutment teeth than the other circumferential cast clasps did. Regardless of applying an occlusal rest or not, RPDs with wrought wire clasps (B1 and B2) had lower SRs than those with cast clasps. However, the mobility of the abutment teeth significantly decreased with RPD placement, even if a wrought wire clasp was applied as a direct retainer.

An additional finding presented here shows that major connector design and RPD placement using lingual plates leads to significantly greater stabilization of the remaining teeth than does the use of lingual bars. The main differences between lingual bars and lingual plates involved their rigidity and contact with remaining teeth. In the present study, we did not conduct an occlusal loading test to evaluate the influence of major connector rigidity on the performance of RPDs and can therefore not speculate as to the influence of this on the stabilization of RPDs. In fact, the influence of major connector design was significant on the SR of the remaining teeth in the absence of a retainer, though did not significantly affect the SR of the abutment teeth. In addition, there was no significant difference in SR between the lingual plate constructed with a Co-Cr alloy and that constructed with PMMA, while there was significant difference in the rigidity of Co-Cr and PMMA. In all, these results suggest that major connector RPD stabilization of the remaining teeth is effective regardless of the connector materials used. On the other hand, SR significantly decreased over the duration of the simulated test only in A4 (Co-Cr), though no evidence of material wear was observed on the internal surface of this device. The retentive force of A4 was lower than that of A5, while there was no significant difference in retentive force between A4 and A5. This may underlie the greater reduction in retentive force and subsequent stabilization of the lingual plate.

Interestingly, we report that the retentive force decreased between the baseline and the end of the simulated test, while no significant changes were found in the SRs of the abutment teeth over the duration of simulated RPD insertion and removal testing. Contrary to our expectations, these results indicate the stabilizing effect of the RPD on the abutment teeth is not necessarily reduced even when its retentive force is decreased. Kim et al. further evaluated changes in the retentive forces of several types of experimental RPD retainers throughout repeated cycles of simulated insertions and removals. This group reported that decreases in the retentive force of Co-Cr alloy clasps were significant across the cycles,
while wrought wire clasps retained their retentive force until the final cycle sequence\textsuperscript{14}. Our findings are in general agreement with these, also indicating decreased retentive force with repeated simulating RPD insertion and removal\textsuperscript{14,15}. It has also been suggested in several previous studies that the retentive force of Co-Cr alloy clasps decreases with repeated RPD insertion and removal because Co-Cr alloy clasps are easily and permanently deformed as compared to wrought wire clasps\textsuperscript{14,22,28}. However, the results of the present study indicate that any permanent deformations in Co-Cr alloy clasps are so small as to not affect the stabilizing effects of RPD on abutment teeth.

Periotest M, which was used in the present study, has also been used to measure tooth mobility and osseointegration of dental implants in previous reports\textsuperscript{29,30}. As shown in Table 2, Periotest results have been shown to correlate with conventional clinical assessments of tooth mobility and the method is effective for the detailed and objective assessment of tooth mobility\textsuperscript{31}. Using Periotest, we were able to evaluate tooth mobility in great detail and also to calibrate the artificial periodontal ligaments in our experimental models such that they accurately simulated weakened tooth mobility, as in cases of periodontal disease.

The material and thickness of the artificial periodontal ligament use in the present study were previously reported in an \textit{in vitro} study and found to have an elastic modulus in the same range of that of the real oral cavity\textsuperscript{18,24}. On the other hand, occlusal loading testing, which simulated the clinical conditions of the oral cavity, was not conducted here given that the present study focused only on the effects of simulated insertion and removal on tooth stabilization. However, we did find that the experimental RPDs displaced slightly towards the underlying soft tissue during insertion and removal testing, requiring the use of artificial mucosa for permitting the displacement of RPDs during simulation of RPD insertion and removal.

Various occlusal stresses in the oral cavity may be placed on RPDs, causing them to rotate or migrate towards the underlying tissue during functional jaw movements including mastication\textsuperscript{32}. Damage to experimental RPDs and evidence of material wear on the internal surfaces of the lingual plates, observed here via SEM imaging, was caused by simulated insertion and removal testing in the present study. These results may be relatively small compared to those found in the real, human oral cavity. Additionally, we have not evaluated the surface changes of the model teeth from the simulation models for RPD insertion and removal testing. Thus, the influences of the surface wear of model teeth on PTV and SR have never been considered. To clarify the effect of each component on tooth stabilization, each component of the experimental RPDs was evaluated independently. Therefore, some of the RPD designs used in this study (such as A1–3 in Fig. 1 or B1–3 in Fig. 2) are not recommended for use clinically to stabilize remaining teeth because they would not be suitable under clinical conditions. Further

CONCLUSION

The results of the present study suggest that cast clasps are more effective for stabilizing mobile abutment teeth than wrought wire clasps for mandibular Kennedy Class I dental arches. Furthermore, we report here that major connectors contacting remaining teeth are more effective at stabilizing them than the use of no retainer or major connectors without contact with the remaining teeth. In addition, the stabilizing effect of RPDs on the abutment teeth is not reduced even when retentive force is decreased. These results provide clinically valuable information that supports the importance of designs of RPD components that stabilize mobile teeth, and which are needed to protect those remaining teeth weakened by dental disease.

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REFERENCES

1) Svärdström G, Wennström JL. Periodontal treatment decisions for molars: an analysis of influencing factors and long-term outcome. J Periodontol 2000; 71: 579-585.
2) Faggion CM Jr, Petersilka G, Lange DE, Gerass J, Flemming TF. Prognostic model for tooth survival in patients treated for periodontitis. J Clin Periodontol 2007; 34: 226-231.
3) Petridis H, Hempton TJ. Periodontal considerations in removable partial denture treatment: a review of the literature. Int J Prosthodont 2001; 14: 164-172.
4) Graetz C, Schwendicke F, Kahl M, Dörfer CE, Sälzer S, Springer C, \textit{et al.} Prosthetic rehabilitation of patients with history of moderate to severe periodontitis: a long-term evaluation. J Clin Periodontol 2013; 40: 799-806.
5) Devlin H. Immediate addition to acrylic partial dentures. Br Dent J 1995; 178: 309-311.
6) Nunn ME, Fan J, Su X, Levine RA, Lee HJ, McGuire MK. Development of prognostic indicators using classification and
regression trees for survival. Periodontol 2000 2012; 58: 134-142.

7) Schuyler CH. The partial denture as a means of stabilizing abutment teeth. J Am Dent Assoc 1941; 28: 1121-1125.
8) Phoenix RD, Cagna DR, DeFreest CF. Stewart’s clinical removable partial prostodontics. 4th ed. Chicago: Quintessence Publishing Co; 2008. p. 111-112.
9) Rudd KD, O’Leary TJ. Stabilizing periodontally weakened teeth by using guiding plane removable partial dentures. J Prosthodont Dent 1966; 16: 721-727.
10) Stewart KL, Rudd KD. Stabilizing periodontally weakened teeth with removable partial dentures. J Prosthodont Dent 1968; 19: 475-482.
11) Schulte JK, Smith DE. Clinical evaluation of swinglock removable partial dentures. J Prosthodont Dent 1980; 44: 595-603.
12) Phoenix RD, Cagna DR, DeFreest CF. Stewart’s clinical removable partial prostodontics. 4th ed. Chicago: Quintessence Publishing Co; 2008. p. 489-493.
13) Ceconi BT, Asgar K, Dootz E. The effect of partial denture clasp design on abutment tooth movement. J Prosthodont Dent 1971; 25: 44-56.
14) Kim D, Park C, Yi Y, Cho L. Comparison of cast Ti-Ni alloy clasp retention with conventional removable partial denture clasps. J Prosthodont Dent 2004; 91: 374-382.
15) Rodrigues RC, Ribeiro RF, de Mattos Mda G, Bezzon OL. Comparative study of circumferential clasp retention force for titanium and cobalt-chromium removable partial dentures. J Prosthodont Dent 2002; 88: 290-296.
16) Kapur KK, Deupree R, Dent RJ, Hasse AL. A randomized clinical trial of two basic removable partial denture designs. Part I: comparisons of five-year success rates and periodontal health. J Prosthodont Dent 1994; 72: 268-282.
17) Akaltan F, Kaynak D. An evaluation of the effects of two distal extension removable partial denture designs on tooth stabilization and periodontal health. J Oral Rehabil 2005; 32: 823-829.
18) Igarashi Y, Ogata A, Kuroiwa A, Wang CH. Stress distribution and abutment tooth mobility of distal-extension removable partial dentures with different retainers: an in vivo study. J Oral Rehabil 1999; 26: 111-116.
19) Itoh H, Baba K, Aridome K, Okada D, Tokuda A, Nishiyama A, et al. Effect of direct retainer and major connector designs on RPD and abutment tooth movements. J Oral Rehabil 2008; 35: 810-815.
20) Jorge JH, Gambusio ET, Vergani CE, Machado AL, Pavarina AC, Cardoso de Oliveira MR. Clinical evaluation of abutment teeth of removable partial denture by means of the Periotest method. J Oral Rehabil 2007; 34: 222-227.
21) Inoue K, Arikawa H, Fuji K, Shinohara N, Kawahata N. Viscoelastic properties of oral soft tissue. 1. A method of determining elastic modulus of oral soft tissue. Dent Mater J 1985; 4: 47-53.
22) VallittuPK, KokkonenM. Deflection fatigue of cobalt-chromium, titanium, and gold alloy cast denture clasp. J Prosthodont Dent 1995; 74: 412-419.
23) Bridgeman JT, Marker VA, Hummel SK, Benson BW, Pace LL. Comparison of titanium and cobalt-chromium removable partial denture clasps. J Prosthodont Dent 1997; 78: 187-193.
24) Xilin J, Sato M, Nishiyama A. Influence of loading positions of mandibular unilateral distal extension removable partial dentures on movements of abutment tooth and denture base. J Med Dent Sci 2004; 51: 155-163.
25) Goto T. Experimental study in the physiological mobility of the tooth. (in Japanese) Shikwa Gakuho 1971; 70: 1415-1444.
26) Antos EW Jr, Renner RP, Foerth D. The swing-lock partial denture: An alternative approach to conventional removable partial denture service. J Prosthodont Dent 1978; 40:257-262.
27) Langer A. Telescope retainers for removable partial dentures. J Prosthodont Dent 1981; 45: 37-43.
28) Ghani F, Mahood M. A laboratory examination of the behavior of cast cobalt-chromium clasps. J Oral Rehabil 1990; 17: 229-237.
29) Schulte W, d’Hoedt B, Lukas D, Maunz M, Steppeler M. Periotest for measuring periodontal characteristics--correlation with periodontal bone loss. J Periodontal Res 1992; 27: 184-190.
30) Jeong MA, Jung MK, Kim SG, Oh JH. Implant stability measurements in the long-term follow-up of dental implants: a retrospective study with Periotest. Implant Dent 2015; 24: 263-266.
31) Lukas D, Schulte W. Periotest: a dynamic procedure for the diagnosis of the human periodontium. Clin Physiol Meas 1990; 11: 65-75.
32) Watanabe C, Wada J, Mizutani K, Watanabe H, Wakabayashi N. Chronological grey scale changes in supporting alveolar bone by removable partial denture placement on patients with periodontal disease: A 6-month follow-up study using digital subtraction analysis. J Dent 2017; 63: 8-13.