Effect of retention hole designs in artificial teeth on failure resistance of the connection with thermoplastic resin

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This study aimed to evaluate the effect of retention hole designs in artificial teeth on failure resistance of the connection with a thermoplastic denture base resin. Artificial teeth with the following retention hole designs were attached to polyester and polyamide resins: no hole, vertical hole, horizontal hole, and vertical and horizontal holes. An artificial tooth with no hole attached to polymethyl methacrylate was prepared as the control. The load was applied until connection failure occurred between the artificial tooth and resin, and failure resistance was detected. Although the control showed the highest resistance, the artificial tooth with vertical and horizontal holes showed higher resistance than those with other retention hole designs in both thermoplastic resins. Providing vertical and horizontal retention holes in artificial teeth may be effective in improving failure resistance of the connection with thermoplastic resins.

Keywords: Thermoplastic resin, Artificial tooth, Retention hole design, Removable dentures

INTRODUCTION

In removable prosthetic treatment, the presence of metal clasps in the esthetic area is aesthetically and psychologically unfavorable for the patient. This is one reason why patients do not favor removable partial dentures (RPDs)1. Consequently, clasps made of gingival-colored thermoplastic resin materials, such as polyesters and polyamides, have been increasingly used as substitutes for metal clasps. RPDs using gingival-colored clasps reportedly improve oral health-related quality of life compared to RPDs with metal clasps when patients are concerned about esthetics2,3).

Several problems concerning RPDs made of thermoplastic resin have been reported, such as evoking or proceeding inflammation of periodontal tissue around RPD abutment teeth and the detachment of artificial teeth from the denture base1). Previous studies have indicated that oral hygiene instruction and professional care would prevent the inflammation of periodontal tissue covered with RPD components4). Additionally, the periodontal health of abutment teeth with resin clasps in patients with well-maintained oral hygiene does not deteriorate during short-term use5). However, the detachment of artificial teeth from the thermoplastic resin denture base is a more critical problem because any effort by patients or dentists cannot overcome this problem.

The following two strategies have been studied to avoid the detachment of artificial teeth: the application of organic solvents to the ridge lap surface of artificial teeth6) and providing a retention hole in an artificial tooth6,7). A previous study reported that preprocessing the ridge lap surface with organic solvents, e.g., ethyl acetate, would not be effective for improving the bond strength between the artificial tooth and thermoplastic resins6). In contrast, it was reported that retention holes with a large diameter decreased the fracture resistance of the artificial tooth, although it increased the strength of the connection with thermoplastic resins8).

There are few reports on the retention hole design of artificial teeth, and the ideal design of the retention hole for RPDs made of thermoplastic resins remains to be examined. Reportedly, with RPDs made of acrylic resins, the vertical groove increases the bond strength more effectively than the horizontal groove9), suggesting that the direction of the retention holes might affect failure resistance of the connection between the artificial tooth and denture base. However, the fracture resistance of the artificial tooth might depend on the retention hole design, including the direction of the hole, which is similar to the diameter of the retention hole9). Therefore, the appropriate design of retention holes for RPDs made of thermoplastic resins should be examined in terms of failure resistance of the connection between the artificial tooth and denture base and the fracture resistance of the artificial tooth.

This study aimed to investigate the effect of retention hole designs on failure resistance of the connection between artificial teeth and thermoplastic denture base resins based on the failure load and failure mode, including fracture of the artificial tooth. The
null hypothesis was that there would be no significant
difference in failure resistance of the connection between
the retention hole designs.

MATERIALS AND METHODS

Specimen preparation
Each specimen consisted of a maxillary right central
incisor artificial tooth, and denture base resin was
prepared to measure the failure load of the connection
between the artificial tooth and denture base resin (Figs.
1A–C). Two thermoplastic denture base resins and
a conventional compression-molded resin were used:
polyester (PE; EstheShot Bright, i-Cast, Kyoto, Japan)
and polyamide (PA; Lucitone FRS, Dentsply Sirona,
York, PA, USA), and polymethyl methacrylate (PMMA;
Acron, GC, Tokyo, Japan) (Table 1). A retention hole with
a 1.6-mm diameter was provided on a commercial brand
composite resin artificial tooth (Endura Anterio, Shofu,
Kyoto, Japan) using a custom-made jig and a milling
machine (LittleMilling9, Toyo Associates, Tokyo, Japan).
The artificial teeth were classified based on the following
four retention hole designs: no hole (N), horizontal hole
(H), vertical hole (V), and vertical and horizontal holes
(VH) (Fig. 2). The experimental groups of specimens
were defined based on the combinations of retention hole
designs and denture base resins, as shown in Table 2.
We used an artificial tooth with no hole design combined
with PMMA was used as the positive control.

For specimen preparation, an artificial tooth was
placed on a wax pattern. The angle of the central axis
between the artificial tooth and denture base resin was
45° (Fig. 1B). Each wax pattern was invested in a dental
stone (Newplastone II, GC) using flasks. The flask was
warmed in hot water and then split to wash the wax. In
the PE and PA groups, the thermoplastic resin specimens
were injected using an injection-molding system (MIS-
II, i-Cast) in accordance with the manufacturer’s
instructions (Table 1). In the control group, PMMA was
polymerized in a water bath at 70°C for 90 min, then

![Fig. 1 Dimensions (mm) of the specimen and loading condition. A: Dimensions (mm) of each side of the denture base. B: The angle of the central axis between the artificial tooth and denture base is 45°. C: The specimen (a) is fixed to the custom jig (b) by the metal plate (c) so the central axis of the denture base is parallel to the custom jig. The load is applied vertically to the tip of the artificial tooth via a loading jig (d).](image)

Table 1  Materials used in this study

| Constituent | Material | Manufacturer | Processing method                                                                 | Lot number          |
|-------------|----------|--------------|-----------------------------------------------------------------------------------|---------------------|
| Denture base resin | Polyester | EstheShot Bright | Nissin, Kyoto, Japan | Injection molding technique; drying condition 90°C for 4 h, heat-processed at 280°C for 20 min | 7A3333980 |
| Denture base resin | Polyamide | Lucitone FRS | Dentsply Sirona, York, PA, USA | Injection molding technique; heat-processed at 300°C for 17 min | 150924A |
| Denture base resin | PMMA | Acron | GC, Tokyo, Japan | Heat-polymerized, compression molding technique; heat-processed at 70°C for 90 min, then 100°C for 30 min, and cooled to 25°C | Powder: 1906241, Liquid: 1912031 |

PMMA: polymethyl methacrylate, UDMA: urethane dimethacrylate, EDMA: ethylene dimethacrylate
at 100°C for 30 min, and cooled to 25°C. Ten specimens were prepared for each group (n=10/group).

**Measurement of failure load of the connection (fracture resistance)**
To measure the failure loads of the connection between the artificial tooth and denture base as failure resistance, we conducted loading tests according to the Japanese Industrial Standards (JIS) T 6506: 2005 and International Organization for Standardization (ISO) 3336: 1993. The specimens were immersed in distilled water at 37°C for 7 days before the loading tests, and the experiments were performed under uniform atmospheric conditions (temperature: 25°C, relative air humidity: 50%). Each specimen was fixed to the custom jig, and the load was applied using a universal testing machine (Autograph AG-X plus, Shimadzu, Kyoto, Japan) with a crosshead speed of 2.0 mm/min until fracture of the specimens or a reduction of 10% of the maximum load from the peak occurred (Fig. 1C). In this study, the load-displacement curve was recorded. After the loading test, the failure mode of each specimen was determined by observing the specimens or analyzing the load-displacement curves. Then, the failure mode was classified into three categories based on the main cause of failure: detachment of the artificial tooth, fracture of the artificial tooth and/or denture base, or deformation of the denture base resin (Fig. 3).

**Statistical analysis**
Because the Kolmogorov–Smirnov test did not detect the normality of the data, non-parametric statistical analyses were conducted. For each thermoplastic resin, a comparison of the failure loads between the four retention hole designs was conducted using the Kruskal–Wallis test. Then, the group showing the highest fracture load in each thermoplastic resin was compared with the control group using the Kruskal–Wallis test to conduct the comparison among three denture base resins. If the Kruskal–Wallis test showed significance,

![Fig. 3 Images of the specimens after the loading test and classification of failure. Detachment of the artificial tooth (A), fracture of the artificial tooth (B) and denture base (C), deformation of the denture base (D). B and C were summarized as fracture. Illustrations of the upper row show the observation area and view shown in the middle row. Detached artificial tooth (A), fractured artificial tooth (B), and the side surface of the specimens (C and D) are shown in the lower row.](image)

**Table 2** Group names based on the combination of denture base material and retention hole design in artificial teeth

| Group   | Denture base resin (material)   | Retention hole design          |
|---------|---------------------------------|--------------------------------|
| PE-N    |                                 | No hole                        |
| PE-H    |                                 | Horizontal                     |
| PE-V    | EstheShot Bright (Polyester)    | Vertical                       |
| PE-VH   |                                 | Vertical and horizontal        |
| PA-N    |                                 | No hole                        |
| PA-H    | Lucitone FRS (Polyamide)        | Horizontal                     |
| PA-V    |                                 | Vertical                       |
| PA-VH   |                                 | Vertical and horizontal        |
| Control | Acron (PMMA)                    | No hole                        |

PMMA: polymethyl methacrylate
pairwise comparisons were performed using the Mann–Whitney U test with Bonferroni correction. All statistical analyses were performed using SPSS version 23.0 (IBM, Chicago, IL, USA), and a p-value <0.05 was considered statistically significant.

RESULTS

Load-displacement curves
Figure 4 shows the typical load-displacement curves of the PE and control groups. In the PE-VH group, the specimens fractured immediately after the load increased linearly and sharply. This fracture behavior in the PE-VH group was similar to that in the control group. In the PE-V group, the load peaked after the load gradually increased with the increasing displacement. The behavior of the PE-H group was similar to that of the PE-V group, and fracture occurred in some of the 10 specimens in both groups. The displacement at the end of the loading test was smallest in the control group, followed by the PE-VH, PE-H, and PE-V groups in that order. In the PE-N group, detachment of the artificial tooth occurred in all specimens before being visualized on the graph. The PA groups showed a similar tendency of fracture and displacement behaviors, as confirmed in the PE groups.

Failure mode
The classified failure modes of all the groups are shown in Fig. 5. In the control group, fracture of the denture base resin was observed in all the specimens. In the PE-N and PA-N groups, detachment of the artificial tooth from the denture base resin was observed in all specimens. In the groups with horizontal or vertical holes (PE-H, PE-V, PA-H, and PA-V), fracture and deformation of the specimens were observed. In most specimens of the PE-V and PA-V groups, deformation of the denture base resin without fracture of the artificial tooth was observed. In most specimens of the PA-VH group and all specimens of the PE-VH group, fracture of the artificial tooth was observed. Overall, the failure modes of the specimens varied and depended on the retention hole design. Additionally, the same tendencies were observed for both thermoplastic resins.

Failure load of the connection (failure resistance)
The failure loads of the connection between the artificial tooth and denture base in both thermoplastic resins are shown in Fig. 6. In the PE groups, the mean values and standard deviations (N) of the failure loads were 148.6±23.8, 110.8±13.0, 92.0±10.6, and 4.9±1.6 for the PE-VH, PE-V, PE-H, and PE-N groups, respectively. The mean failure load of the PE-VH group was significantly higher than that of the PE-H (p=0.003) and PE-N (p<0.001) groups. The mean failure load of the PE-V group was significantly higher than that of the PE-N group (p=0.001). In the PA groups, the mean values and standard deviations (N) of the failure loads were

![Fig. 4 Load-displacement curve of the polyester and control groups.](image)

![Fig. 5 Number of specimens based on failure mode in each group.](image)
Fig. 6 Mean failure load and standard deviation (N) for each group (n=10).
Results of the PE (A) and PA denture base (B). The asterisk (*) indicates a significant difference between the groups (p<0.05). N, no hole; H, horizontal hole; V, vertical hole; VH, vertical and horizontal holes; PE, polyester; PA, polyamide

Fig. 7 Mean failure loads and standard deviation (N) of the control, PE-VH, and PA-VH groups (n=10). The asterisk (*) indicates a significant difference between the groups (p<0.05). VH, vertical and horizontal holes; PE, polyester; PA, polyamide

133.4±20.4, 94.1±15.8, 94.0±20.1, and 3.5±2.0 for the PA-VH, PA-V, PA-H, and PA-N groups, respectively. The mean failure load of the PA-N group was significantly lower than that of the other groups (p<0.001, 0.012, and 0.017 for the PA-VH, PA-V, PA-H groups, respectively). Because the VH group had the highest fracture load in each thermoplastic resin, the failure loads in the PE-VH group, PA-VH group, and control group were compared. The mean failure load with standard deviation (N) of the control group was 183.2±27.1, which was significantly higher than those of the PE-VH (148.6±23.8, p=0.033) and PA-VH groups (133.4±20.4, p=0.001) (Fig. 7).

DISCUSSION

To the best of our knowledge, this is the first study to examine the effect of retention hole designs of artificial teeth on the failure load of the connection between the artificial teeth and thermoplastic denture base resins based on the failure load and failure mode according to the load-displacement curves. The present study’s results indicated that the experimental groups with both vertical and horizontal holes (PE-VH and PA-VH) showed significantly higher failure loads than the groups without any holes (PE-N and PA-N). Therefore, the null hypothesis was rejected, suggesting that providing vertical and horizontal holes on the artificial tooth would be effective for improving failure resistance of the connection between the artificial tooth and denture base resin.

As the PE-N and PA-N groups showed, the artificial tooth without any retention hole had little failure resistance to connect with the denture base. Conventional acrylic resins, including PMMA, and artificial teeth are chemically bonded by forming an interpenetrating polymer network (IPN) layer during the polymerization reaction. However, for thermoplastic resins, the IPN layer is not formed because the polymerization reaction never occurs during the injection molding of the resins. Therefore, the artificial tooth should be mechanically retained in thermoplastic resins.

In the current study, there was no significant difference between the mean failure loads of the groups with vertical holes (PE-V and PA-V) and those with horizontal holes (PE-H and PA-H). On the other hand, for each thermoplastic resin, the groups with both vertical and horizontal holes (PE-VH and PA-VH) showed higher failure loads than the other groups. The intersection of the two retention holes might increase the structural strength of the thermoplastic resin injected into the retention hole, resulting in an increase in failure resistance of the resin. This could be explained by the results of the load-displacement curve, in which the displacement of the groups with vertical and
horizontal holes was lower than that of the groups with only vertical or horizontal holes when the same load was applied (Fig. 4). Additionally, it could be found in the load-displacement curve that the shape of the curve in the groups with both vertical and horizontal holes (i.e., being fractured immediately after the load increased linearly and sharply) was similar to that of the control group, suggesting that the comprehensive characteristics of the artificial teeth–denture base complex would be dramatically improved with vertical and horizontal holes; thus, it could be acceptable for clinical application as well as conventional RPD fabricated with PMMA. However, the reason why the artificial tooth fractures occurred as the failure mode in most specimens of the groups with vertical and horizontal holes (Fig. 5) was probably that the fracture stress was concentrated in the artificial tooth. In this study, the aforementioned tendency was observed for both thermoplastic resins. This might be because two thermoplastic resins used in this study would have a similar mechanical property to each other. Lee et al. reported that there was no significant difference in the proportional limit (Estheshot bright: 31.3 MPa, Lucitone FRS: 31.6 MPa) and flexural strength (Estheshot bright: 60.8 MPa, Lucitone FRS: 64.3 MPa) between both thermoplastic resins.12,13 Yamazaki et al. also reported that there was no significant difference in flexural strength (Estheshot bright: 64.9 MPa, Lucitone FRS: 66.2 MPa).13

The mean failure loads of the groups with vertical and horizontal holes, which showed the highest failure load in the PE (148.6 N) and PA (133.4 N) groups, were significantly lower than those of the control group (183.2 N) in this study (Fig. 7). The maximum occlusal force is 200–600 N in older adults, including RPD wearers.14 Other studies have shown that the maximum occlusal force at the anterior teeth is approximately 100–200 N in adults with healthy dentition.15,16 According to the JIS T 6506:2005 standard and ISO 3336:1993, the acceptable bonding strength between a resin artificial tooth and the acrylic denture base resin is 110 N. For both thermoplastic resins examined herein, the failure loads and standard deviations (N) of the groups with vertical and horizontal holes (148.6±23.8 and 133.4±20.4 N for the PE-VH and PA-VH groups, respectively) would be acceptable in clinical practice, whereas the fracture loads of almost all the other experimental groups would not be clinically acceptable. Considering only the failure load, the PE-V group (110.8±13.0 N) might also have clinically acceptable resistance. However, as shown in Fig. 4, the displacement of the specimen in the PE-V group was greater than that in the PE-VH group under the same load. Hence, it remains unclear whether it could be clinically acceptable. Furthermore, with the long-term use in the oral cavity, aging of the denture base may affect the failure resistance with the artificial teeth because they are not bonded chemically to each other. It has been reported that the thermoplastic resin deforms by cycling deflection and the elastic modulus changes due to the thermal cycle. Therefore, further studies on these effects and the effects of degeneration by saliva and denture cleansers are required to examine failure resistance between the artificial tooth and thermoplastic denture base with long-term use.

Although our findings suggest that providing vertical and horizontal retention holes on the artificial tooth would be effective for improving failure resistance, the fracture mode of almost all specimens with vertical and horizontal retention holes was fracture of the artificial tooth. If the mechanical properties of the artificial tooth can be strengthened, e.g., by using a milled tooth of a hybrid resin block or a ceramic block, the failure resistance between the artificial tooth and thermoplastic denture base resin might be improved.

This study has some limitations. First, this study examined only two types of thermoplastic resins. There are many other types of thermoplastic resins, so further studies are required. Second, only composite resin teeth were used in this study. Future studies are required to examine the porcelain tooth, an acrylic resin tooth. In addition, a milled tooth of a hybrid resin block or ceramic block should be examined to strengthen the fracture strength of the artificial tooth itself in the future. Finally, in this study, the diameter of the retention hole was set at 1.6 mm. Tashiro et al. reported that the strength of the connection between the artificial tooth and thermoplastic resin depends on the diameter of the retention hole. In a further study, the failure resistance should be examined in terms of the diameter and direction of the artificial tooth.

CONCLUSION

Within the limitations of this study, we found that providing vertical and horizontal retention holes on artificial teeth would be effective for improving failure resistance of the connection between the artificial teeth and thermoplastic denture base resin.

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