Rapid development in adhesive dentistry has opened a wide range of applications for different materials, designs, and treatment plan options. One of these applications is for resin-bonded fixed dental prostheses (RBFDPs). Many reports have been published highlighting the success rates regarding the use of veneers and RBFDPs.\textsuperscript{1–6}

Restoring a single-tooth anterior edentulous span has been a challenge for many years. Restoration may be necessary due to premature tooth loss from trauma, congenitally missing teeth, or periodontitis. Treatment options available to restore a missing lateral incisor include orthodontic treatment, implant treatment, and prosthetic treatment.\textsuperscript{7} Treatment choice should be primarily concerned with conserving tooth structure by using the least invasive approach, bearing in mind careful case selection for longevity of the prostheses.\textsuperscript{8}

RBFDPs have been used to restore single teeth anteriorly or posteriorly with strict guidelines for achieving moderate- to long-term serviceability.\textsuperscript{9} Moreover, RBFDPs may be applied in young patients, allowing preservation of tooth structure. The use of conventionally (ie, palatally) retained RBFDPs is well documented in the literature, with mid-term and long-term survival rates.\textsuperscript{1–3} Recently, with the increased focus on

\textbf{Purpose:} To evaluate the effect of three two-retainer designs of a resin-bonded fixed dental prosthesis (RBFDP) on fracture resistance. \textbf{Materials and Methods:} A total of 21 three-unit, all-ceramic RBFDPs were fabricated to replace a missing maxillary lateral incisor. The prostheses were divided into three groups of 7 each: Group L (labial RBFDP); Group ML (modified labial RBFDP, fabricated the same as in Group L with additional preparation that included a shallow proximal groove at the pontic side); and Group P, an all-ceramic palatal RBFDP that acted as control. Preparations were done on the maxillary left central incisor and canine of a typodont model, and 21 epoxy resin models were duplicated for the three groups. The RBFDPs were designed using CAD software and constructed using the heat-pressed technique, after which the prostheses were bonded to their corresponding epoxy resin model according to the manufacturer’s instructions. A fracture resistance test was performed on all specimens following aging. Data were analyzed using one-way ANOVA. \textbf{Results:} The highest fracture load values were recorded in Group P (547.5 N), followed by Group ML (462.6 N) and then Group L (418.3 N). The difference among the three designs was not statistically significant (F = 2.5, P = 0.1). \textbf{Conclusion:} Both labial and modified labial RBFDPs could be a viable alternative treatment option for replacement of missing maxillary lateral incisors. \textbf{Int J Prosthodont 2021;34:348–356. doi: 10.11607/ijp.6379}
esthetic enhancement and rapid development in bonding, labial veneer–retained fixed dental prostheses have emerged through clinical reports as a possible treatment option.

The literature is rich with in vivo and in vitro publications evidencing the survival of laminates; however, only a handful of clinical reports in the literature have described laminate-retained fixed dental prostheses as a line of treatment. Promising results have been reported despite the short-term follow-ups of up to 5 years.

Since retainer design can affect the strength and failure mode of an RBFDP and due to lack of scientific data regarding the clinical performance of a labial veneer–retained RBFDP, in vitro mechanical and thermal testing are encouraged as a step closer to clinical simulation.

The present study aimed to evaluate the effect of three two-retainer designs of an RBFDP on fracture resistance, with the null hypothesis that the retainer design would not affect the performance and failure mode of an RBFDP.

**MATERIALS AND METHODS**

Three typodont teeth sets of the maxillary central incisor and canine were screwed in their sockets and checked for correct seating and position. Three RBFDP design preparations were tested: Labial reduction (Group L); labial reduction with a proximal shallow groove (Group ML); and palatal reduction (Group P) (Fig 1).

In Group L, a window preparation with no incisal coverage was performed, and cuts of 0.5-mm depth were prepared to reduce the labial surface of the typodont teeth in two planes. The labial surfaces were painted with a water-insoluble paint to standardize the amount of reduction and prepared using a diamond stone (856 014 F FG, ökoDENT). The preparation extended cervically 0.5 mm above the gingival margin to produce a chamfer finish line of 0.5 mm. The preparation was extended proximally at the pontic side in a slice fashion to end just before the proximo-palatal line angle. All sharp lines and point angles were smoothed and rounded using finishing stones (Fig 2a).

In Group P, the palatal RBFDP preparation design, a wheel diamond stone instrument (909/018) was used to place four 0.5-mm grooves along the lingual surfaces of the typodont teeth. The palatal surfaces were then painted with a water-insoluble paint for calibration. Cervical tooth reduction was performed using a round-end diamond stone (856 014 F FG, ökoDENT) to create a 0.5-mm chamfer finish line, where the stone was held parallel to the long axis of the teeth. The reduction proximally neighboring the intact tooth was extended short of the contact area, whereas the reduction adjacent to the edentulous area was extended beyond the contact area in a slice fashion to end before the labio-proximal line angle. All sharp lines and point angles were smoothed and rounded using finishing stones (Fig 2b). The depth of the preparation was checked using the previously prepared index and a periodontal probe.

Impressions for Groups L and P were done using two acrylic resin special trays and a single-viscosity, medium-body rubber base impression material (Monophase Medium, 3M ESPE). Using an auto-mixing machine (Pentamix 2, 3M ESPE), the impression material was dispensed into the tray and impression syringe, then injected around the abutments. The tray was loaded immediately and supported until the final setting. Following setting, the tray was removed and checked for voids.

The trays were boxed using modeling wax and poured with epoxy resin material (Kemapoxy 150, CMB). The epoxy material is supplied as two liquids, which were mixed together according to the manufacturer’s instructions.
in a 1:2 ratio and poured into the impression. The models were then left to set under 2.5-bar pressure at room temperature for 24 hours in a curing machine (Vertex MultiCure, Vertex Dental). Two epoxy models were then removed and checked for voids. Master casts were duplicated using addition silicone duplicating material (REPLISIL 22 N, Dent-E-Con). The L and P molds were poured in epoxy resin seven times in each group.

The design in Group ML included two proximal grooves of 0.5-mm depth and 2.0 mm bucco-lingual width. The Group L epoxy model was modified to produce the modified labial veneer prosthesis design.

The cast was placed on the same laboratory milling machine surveyor (Paraflex, BEGO) to prepare the grooves parallel to the common path of insertion. The proximal surfaces were painted with a blue marker to localize and determine the sites and dimensions of the grooves. A tapered stone with a round end was used to prepare the grooves. The path of insertion was checked, and any undercuts were removed (Fig 3). The epoxy cast was then duplicated in the same manner as the former designs to produce seven epoxy resin models (Fig 4).

One epoxy resin cast from each group was sprayed with powder and scanned using a three-axis blue scanner. The designs were performed using Exocad software. The prostheses were digitally designed with a connector thickness not less than 12 mm$^2$, and polymethyl methacrylate (PMMA) blanks were milled to produce standardized patterns that were used to produce a pressed lithium disilicate ceramic prosthesis for each of the three designs (Figs 5 to 7).

A PMMA blank (98 × 15 mm S) was used to produce standardized patterns for each group. A five-axis dry milling machine (VHF K5, P&S) was used to mill 21 patterns corresponding to the three designs. Each resin pattern was seated on its
Sugar-rich foods and beverages that are high in fermentable carbohydrates and acidic environments can promote bacterial overgrowth, leading to tooth decay. These conditions can be exacerbated by factors such as poor oral hygiene, inadequate saliva production, and the use of sugary drinks or foods that are acidic or contain high levels of sugar. To prevent tooth decay, individuals should maintain good oral hygiene habits, including brushing twice daily with fluoride toothpaste, flossing once a day, and regular dental check-ups.

**Bonding Protocol**

Epoxy dies were sandblasted with aluminum oxide of 50-µm particle size for 5 seconds at a 10-cm distance and with a pressure of 2.5 bar. They were then cleaned with steam. At the time of bonding, the prepared surfaces were cleaned by spraying 96% scent-free alcohol and were then gently dried. A layer of silane coupling agent (Pre-Hydrolized Silane Porcelain Primer, BISCO) was then applied and air dried after 1 minute.

The patterns were then placed in the ring for the pressing production procedure using lithium disilicate IPS e.max (Ivoclar Vivadent) HT BL2 ingots. A thin layer of IPS Ceram Glaze (Ivoclar Vivadent) was applied to the restorations and fired (Fig 11).

**Fig 4** Modified labial RBFDP preparation (incisal view).

**Fig 5** (right) Connector measurements of palatal RBFDP.

**Fig 6** (below left) Connector measurements of labial RBFDP.

**Fig 7** (below right) Connector design and measurements of modified labial veneer prosthesis.
**Fig 8** Palatal RBFDP PMMA pattern (incisal view).

**Fig 9** Labial RBFDP PMMA pattern (incisal view).

**Fig 10** Modified labial RBFDP PMMA pattern (palatal view).

**Fig 11** Fitted palatal RBFDP on its corresponding epoxy resin die.

**Fig 12** Seating the resin guide.
Lithium disilicate RBFDPs were surface treated. One prosthesis was prepared at a time using 5% hydrofluoric acid gel (IPS Ceramic Etching Gel, Ivoclar Vivadent) applied for 20 seconds. The prosthesis was then washed and dried. Then, the intaglio surface was silanized for 1 minute and dried with air spray.

Bonding of RBFDPs was done using a dual-cure adhesive resin cement (Panavia F 2.0, Kuraray). The specimen was then seated using a specially designed resin guide that was previously fabricated to secure the prosthesis seating on its corresponding dies and loaded into a 5-kg loading device for 5 seconds. The cement was initially light cured (D-Light, Coxo) at the cervical areas for 2 to 3 seconds (Fig 12). The resin guide was removed, excess resin was scraped with a sharp scaler, and OxyGuard was applied on the margins of the restorations to complete polymerization. The cement was further cured with a soft start mode for 5 seconds, and then the curing was completed for 10 seconds at 1,000 MW/cm² from the labial and lingual directions. After completion of bonding of the RBFDPs, the models were stored in water at room temperature for 24 hours prior to testing.

**Testing**

In this study, the restorations were thermocycled to 1,000 cycles. Dwell times were 25 seconds in each water bath (Robota automated thermal cycler, BILGE) with a lag time of 10 seconds. The temperature varied from 5°C to 55°C. Mechanical aging test was conducted using a chewing simulator (ROBOTA Chewing Simulator) under a weight of 50 N of chewing force at the center of the pontal palatally using a metallic rod with a round tip (3.4-mm diameter) attached to the upper movable compartment of the testing machine and traveling at a crosshead speed of 1 mm/minute with a tin foil sheet in between to achieve a homogenous stress distribution. The load at failure was manifested by an audible crack and confirmed by a sharp drop at the load deflection curve, recorded using computer software. The load required to fracture was recorded in Newtons. Failures were examined on a true magnified image using a digital single-lens reflex camera (D5300, Nikon) with macro lens (AF-S VR Micro-NIKKOR 105 mm f/2.8G IF-ED) and ink dye.

**Fracture Resistance Test**

Fracture resistance test was done by compressive loading applied at a 135-degree angle after fixing the sample in a specially designed 45-degree steel angle jig at the center of the pontial palatally using a metallic rod with a round tip (3.4-mm diameter) attached to the upper movable compartment of the testing machine and traveling at a crosshead speed of 1 mm/minute with a tin foil sheet in between to achieve a homogenous stress distribution. The load at failure was manifested by an audible crack and confirmed by a sharp drop at the load deflection curve, recorded using computer software. The load required to fracture was recorded in Newtons. Failures were examined on a true magnified image using a digital single-lens reflex camera (D5300, Nikon) with macro lens (AF-S VR Micro-NIKKOR 105 mm f/2.8G IF-ED) and ink dye.

Data analysis was performed using descriptive statistics for the results of each group. One-way analysis of variance (ANOVA) was performed to detect significance between subgroups. Chi-square test was performed for distribution of fracture sites. Statistical analysis was performed using In Stat Graph-Pad statistics for Windows. *P* values ≤ .05 were considered to be statistically significant in all tests.

**RESULTS**

Fracture resistance results for all groups are summarized in Table 1. The mean fracture resistance value recorded for Group L after chewing simulation was 418.4 N.

**Table 1  Comparison of Fracture Resistance Results (Mean ± Standard Deviation) Among All Groups**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ± SD</th>
<th>Range</th>
<th>95% confidence intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Lower</td>
</tr>
<tr>
<td>Retainer design</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labial</td>
<td>418.377 ± 39.177</td>
<td>354.57</td>
<td>474.94</td>
</tr>
<tr>
<td>Modified labial</td>
<td>462.601 ± 90.029</td>
<td>257.11</td>
<td>655.96</td>
</tr>
<tr>
<td>Palatal</td>
<td>547.52 ± 94.914</td>
<td>334.33</td>
<td>775.54</td>
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</table>

ANOVA

<table>
<thead>
<tr>
<th><strong>F</strong></th>
<th><strong>P</strong></th>
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<tbody>
<tr>
<td>2.477</td>
<td>.1121</td>
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</tbody>
</table>

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with a minimum value of 354.6 N and a maximum value of 474.9 N. For Group ML, the mean resistance value was 462.6 N, with a minimum value of 257.1 N and a maximum value of 347.2 N. For Group P, the mean resistance value was 547.5 N, with a minimum value of 334.3 N and a maximum value of 775.5 N (Table 1).

It was noted that the highest mean values were recorded in Group P, followed by Group ML and then Group L. The difference among the groups was not statistically significant, as indicated by ANOVA ($F = 2.477, P = .1121$) (Fig 13). No failure—neither abutment fracture nor prosthesis fracture—occurred during thermomechanical fatigue in terms of debonding. Moreover, there were no debonding failures in all specimens.

The fracture site for Group L occurred predominantly at the mesial connector (Fig 14) and the central incisor retainer ($n = 3$ [42.9%] for both). The least amount of fractures happened at the canine retainer ($n = 1$ [14.9%]). In Group ML, the fracture location was predominantly at the abutment (Fig 15) ($n = 4$ [57.1%]), followed by the pontic ($n = 3$ [42.9%]). In Group P, the fracture site was located predominantly at the mesial connector (Fig 16) ($n = 4$ [57.1%]), followed by the abutment ($n = 2$ [28.6%]), while the minority were located at the pontic ($n = 1$ [14.9%]) (Table 2). The difference between groups was statistically significant, as indicated by chi-square test ($\chi^2 = 274.25, P = .0001$).

**DISCUSSION**

Three designs of an all-ceramic two-retainer RBFDP to replace a missing maxillary lateral incisor were evaluated: Group L, a labial veneer–retained RBFDP; Group ML, prostheses fabricated with an additional preparation that included a shallow proximal groove; and Group P, a palatally retained RBFDP that acted as control.
The highest mean fracture resistance values were recorded in Group P (547.5 N), followed by Group ML (462.6 N), while the lowest mean values were recorded in Group L (418.4 N). The difference among the groups was not statistically significant, as indicated by ANOVA (F = 2.477, P = .1121). The null hypothesis—that the retainer design would not affect mean fracture resistance values—was accepted.

This study was done to test and compare the performance of two designs of labial RBFDPs to that of a conventional (palatal) glass-ceramic RBFDP. RBFDPs have been used as a minimally invasive treatment option to restore single missing anterior teeth, mainly in young patients. Unlike conventional fixed dental prostheses, little sound tooth structure is removed for RBFDPs.17

As aesthetics become a rising concern, replacement of congenital missing lateral incisors may need additional enhancement of the overall smile by improving the anterior teeth color and/or shape. For that purpose, case reports have proposed replacing missing lateral incisors with a labially retained RBFDP rather than with the conventional palatal retainer.11–15

As a result of the complex stresses occurring in the anterior area and due to failures at the connector site reported by Oh et al,18 a second design for a labial RBFDP that includes shallow proximal grooves in the preparation was proposed. This design is supported by many reports16,19–22 to increase the connector size and provide more retention for the whole system.

The mean adult occlusal force reported in the anterior area is 200 N.23 Within the limitations of this study, all designs could be safely used clinically in the anterior area. Forces subjected to the three groups were directly and had fracture test values exceeding the documented bite forces of 155 to 200 N reported for the anterior zone, and therefore may be tested clinically.

Table 2  Frequency Distributions of Failure Site and Type for All Groups

<table>
<thead>
<tr>
<th>Failure site</th>
<th>Preparation design groups, n (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Labial</td>
<td>Modified labial</td>
</tr>
<tr>
<td>Connector</td>
<td>Mesial  3 (42.857)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>Distal  0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Retainer</td>
<td>Central  3 (42.857)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>Canine  1 (14.857)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Pontic</td>
<td>0 (0)</td>
<td>3 (42.857)</td>
</tr>
<tr>
<td>Abutment</td>
<td>0 (0)</td>
<td>4 (57.143)</td>
</tr>
</tbody>
</table>

CONCLUSIONS

The three designs tested in this study performed similarly and had fracture test values exceeding the documented bite forces of 155 to 200 N reported for the anterior zone, and therefore may be tested clinically.
Nevertheless, patient selection for an RBFDP is restricted to patients with normal occlusion and absence of any parafunctional habits, where the pontic is placed out of occlusion in all centric and eccentric movements. Furthermore, labial designs for RBFDPs should be restricted to the need to change an abutment’s color or shape.

ACKNOWLEDGMENTS

The authors report no conflicts of interest.

REFERENCES
