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Marginal fit and retention force of zirconia resin-bonded fixed dental prostheses in the posterior region with different designs

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Abstract *Background/purpose:* Retainer debonding of resin-bonded fixed dental prostheses (RBFDPs) is one of the major reasons for their lower survival rates than fixed dental prostheses (FDPs) with full-coverage crowns. Recent advances in milling technology have enabled the fabrication of RBFDPs with complex retainers (D-shaped designs). This study aimed to assess the marginal fit and retention force of zirconia RBFDPs with inlay-, L-, and D-shaped designs to clarify their clinical applications.
Materials and methods: Three abutment teeth models without maxillary second premolars were created using inlay-, L-, and D-shaped retainer designs. The zirconia RBFDPs were designed and fabricated according to the manufacturer's instructions ($n = 10$). The marginal gap was measured using the silicone replica technique. Zirconia frameworks were bonded to the abutment teeth using resin cement. Tensile test was conducted after thermal cycling and dynamic loading tests. The loads during debonding or fracture were recorded. The failure pattern was analyzed by observing the fracture surface using a scanning electron microscope.
Results: D-shaped RBFDPs showed a significantly larger marginal gap than inlay- and L-shaped RBFDPs ($P < 0.05$). However, the mean marginal values were clinically acceptable (<120 μm). The D-shaped model exhibited the highest tensile strength in the tensile tests. The inlay-

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shaped and most of the D-shaped RBFDPs experienced debonding with cohesive failure, whereas the L-shaped RBFDPs showed fractures near the connector.

Conclusion: The D-shaped retainer design was superior to the inlay- and L-shaped designs with respect to the inhibition of retainer debonding. However, the marginal fitness needs to be improved.

Introduction

Fixed dental prostheses (FDP) have been widely used for single missing teeth in the posterior region because of their superior fitness, relatively short treatment time, and longevity.[1–3] However, conventional FDP is a full-coverage crown that requires extensive tooth structure removal and may sometimes cause complications, such as pulpal symptoms of the abutment tooth.[4,5] Resin-bonded FDP (RBFDP) may be considered be an alternative since it only requires the removal of a portion of the tooth structure; thus, it is more esthetic and minimally invasive, thereby reducing the risk of pulp treatment. Additionally, RBFDPs are functionally superior because it is possible to maintain the cusps, which maintains the occlusal state.[6,7]

However, a previous study showed that the 5-year survival rate of FDPs was 93.8 %, whereas that of RBFDPs was 87.7 %, suggesting that the long-term prognosis of RBFDPs is an issue.[8] The most frequent contingency leading to the lower survival rates of RBFDPs is debonding of the retainers.[9–11] According to a systematic review, a report investigating the 5-year survival rates of RBFDPs suggested that 15 % of 23.8 % of technical complications were debonding.[9] Similarly, another randomized controlled trial showed that 12.2 % of the 17 % of 5-year failure rate of all-ceramic RBFDPs was due to debonding.[12] Therefore, to maintain the long-term function of RBFDPs and improve their prognosis, treatment techniques that are less likely to cause debonding should be considered.

In the posterior region, dental alloys have been used extensively as restoration materials because of their good rigidity and excellent machinability; the frameworks are designed as inlay-, L-, and D-shaped, in which the D-shaped retainers showed excellent performance in terms of mechanical strength and retention resistance.[13] Moreover, pin-retained RBFPDs showed high dislodgement resistance compared to conventional three-unit RBFPDs.[14] Dental zirconia has been widely utilized recently in place of conventional alloys because of increasing esthetic demands and awareness of allergy avoidance.[15,16] The fabrication of dental zirconia restorations differs from that of dental alloys because of the requirement for a milling procedure, which could affect the fit accuracy of the frameworks. However, data on the fitness of zirconia RBFDPs in the posterior region are few.

Regarding the retainer design of zirconia RBFDPs, clinical applications of inlay[17] and L-shaped[18] frameworks have been reported. An in vitro study showed that increasing the number of L-shaped wings improves the retention force of RBFDPs.[19] Studies have also investigated the fracture resistance and patterns of different retainer designs, indicating that onlay and inlay retainers enhance the biomechanical performance of the restoration.[20,21] However, the D shape, which showed a good prognosis for metal frames, is lacking in the literature in terms of fabrication using dental zirconia because of the difficulty in designing and fabrication using a computer-aided design (CAD)/computer-aided manufacturing (CAM) system.

Therefore, this study aimed to evaluate the marginal fit and retention force of zirconia RBFDPs in the posterior region with different designs, including D-shaped ones, and clarify the relationship between retainer design and debonding. The first null hypothesis was that retainer design does not affect marginal fit. The second null hypothesis was that retainer design has no effect on retention force.

Materials and methods

Fabrication of specimen

Tooth preparation was performed on a jaw model using melamine teeth (D18FE-500A-QF, Nissin Dental Products INC., Kyoto, Japan) assuming a missing right maxillary second premolar. The abutment teeth (first premolar and first molar) were prepared in inlay-, L-, and D-shaped. The tooth preparation design for each group is shown in Fig. 1. For the inlay-shaped RBFDP, occlusal boxes were prepared with a depth of 1.5 mm, and a proximal box was formed 2 mm deeper than the occlusal box. For the L-shaped RBFDP, a proximal rest was prepared, and the wings ranged from the deficient side to beyond the distal angle of the nondeficient side. For the D-shaped RBFDP, the molar encloses the proximal palatal cusp, and the first premolar encloses the palatal cusp. The palatal side of the L- and D-shaped RBFDPs were prepared with an axial reduction of 0.9 mm within the enamel. The margin was set 1 mm above the gingival cuff, and a chamfer finish line was prepared. Tooth reduction was assessed using the silicone index (Exafine Putty Type, GC Co., Tokyo, Japan).

After preparation of the abutment tooth, impressions were made using a silicone impression material (Exafine Regular&Hard Type, GC Co.), and then pattern resin (Pattern ResinXF, GC Co.) was injected into the impression material to create a casting pattern. Three master models were fabricated by casting and polishing a cobalt-chromium alloy (CobarionEX, SHOFU INC., Kyoto, Japan).

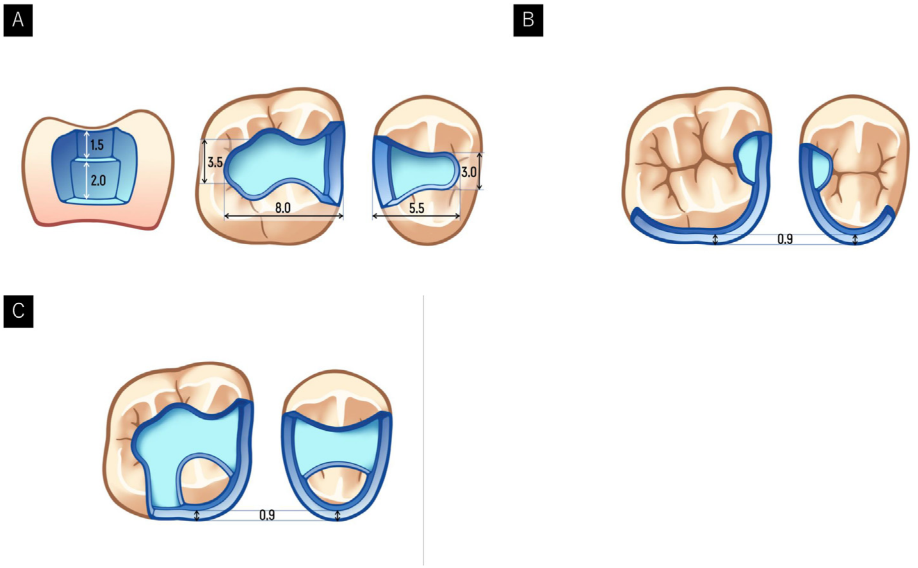

Figure 1 Preparation of master models. The numbers indicate the amount of tooth reduction. (A) Inlay-shaped resin-bonded fixed dental prostheses (RBFDPs), (B) L-shaped RBFDPs, (C) D-shaped RBFDPs.

Three master models were made into the plaster models and scanned with a laboratory scanner (AutoScan-DS-EX Pro Dental 3D Scanner, SHINING3D, Hangzhou, China). The RBFDPs frameworks were designed using a CAD/CAM software (DentalCAD, Exocad GmbH, Darmstadt, Germany) (Fig. 2).

During the design process, the cement range was set from 1 mm inward from the finish line, and the cement space was set as 50 μm. The pontic form is designed as a ridge lap. The connector area was approximately 9 mm^2. Dental zirconia discs (Noritake Katana Zirconia HTML PLUS, Kuraray Noritake Dental Inc., Tokyo, Japan) were milled on a 5-axis milling machine (MD-500, Canon Electronics Inc., Tokyo, Japan) and sintered using a sintering machine (inFire HTC speed, Dentsply Sirona Inc., Charlotte, NC, USA) according to the manufacturer's instructions. Ten frameworks were fabricated for each group.

Evaluation of marginal fit

Marginal fit was evaluated using the replica technique.[22] The bonding surfaces of the zirconia frameworks were filled with black silicone (BITE-CHECKER, GC Co.) and placed on the master model under finger pressure until setting. The frameworks were then removed, and white silicone (FIT-CHECKER, GC Co.) was placed onto the black silicone to prevent its deformation. After setting, the silicone replica was removed from the master model and cut in the mesiodistal and buccolingual directions, as shown in Fig. 3. The thickness of the black silicone was measured using a micron-depth height-measuring machine (KY-60, Nisshooptical Co., Ltd., Saitama, Japan) at eight points in each framework.

Bonding process and aging test

The bonding surface of the abutment tooth and framework was cleaned with distilled water and ethanol swabs using an ultrasonic machine. A tooth primer (Tooth Primer, Kuraray Noritake Dental Inc.) was applied to the abutment tooth for a 20-s pause, then air-dried for 5 s. As for the frameworks, the bonding surface was air-borne particle abraded with alumina particles (Al_2O_3, 50-μm particle size, 0.4-MPa pressure, 10-mm spray distance, 20-s duration), applied with ceramic primer (Ceramic Primer Plus; Kuraray Noritake Dental Inc.), and acclimated with weak air for 5 s. Subsequently, the resin cement (Panavia V5, Kuraray Noritake Dental Inc.) was flowed uniformly onto the bonding surface of the frameworks, and the frameworks were set on the abutment tooth with figure pressure. Excess cement was wiped clean using a microbrush. Light irradiation was applied to each surface for 20 s at 5-mm distance using a dental curing light. All specimens were stored in deionized water at 37 °C for 24 h.

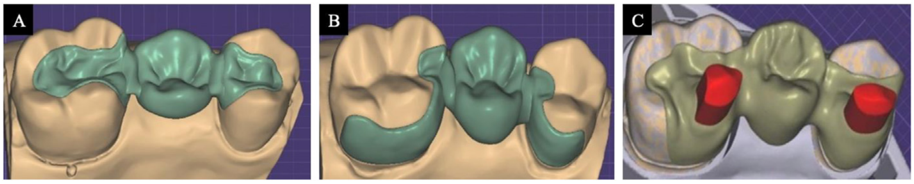

Figure 2 The view of framework design using computer-aided design/computer-aided manufacturing software. (A) Inlay-shaped resin-bonded fixed dental prostheses (RBFDPs), (B) L-shaped RBFDPs, (C) D-shaped RBFDPs.

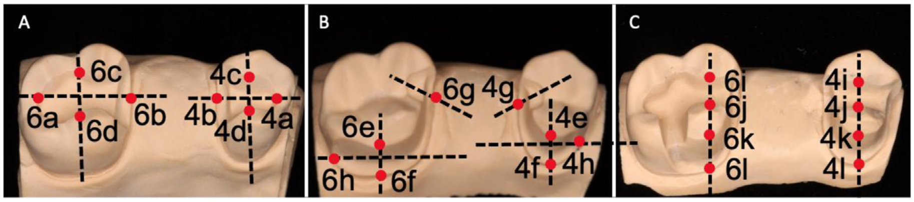

Figure 3 "6" signifies first molar, "4" signifies first premolar. The silicone replicas were cut as the directions of dot lines. Red dots (a—h) are the measurement points for the marginal gap. (A) Inlay-shaped resin-bonded fixed dental prostheses (RBFDPs), (B) L-shaped RBFDPs, (C) D-shaped RBFDPs. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

After the cement was completely cured, all specimens were embedded in acrylic resin (Palapress Vario, Kilzer HmbH, Tokyo, Japan). The specimens were subjected to thermal-cycling in deionized water alternating between 5 and 55 °C for 6000 times to simulate cement degradation and then subjected to 240,000 cycles of dynamic loading in deionized water at 37 °C using an impact and abrasion tester (K655-05, TOKYO GIKEN INC., Tokyo, Japan).[23] A 3 mm-diameter stainless steel ball with a 50 N load was applied from the tooth axis direction to the central fossa of the pontic tooth. The specimens were checked for debonding and fractures every 40,000 cycles.

Tensile test

After the aging test, a 0.81-mm diameter stainless wire loop (Y-107, Nissa chain Co., Ltd., Osaka, Japan) was passed through both tissue sides of the pontic, and a tensile test was performed in the tooth axial direction at a cross-head speed of 2 mm/min using a universal testing machine (Autograph AGS-H, Shimadzu Corporation, Kyoto, Japan) (Fig. 4). The load was recorded when debonding or fracture occurred within the framework. Finally, the fracture patterns of the frameworks were classified, and the surfaces were observed using a scanning electron microscope (SEM) (JSM-7900F, JEOL Ltd., Tokyo, Japan).

Statistical analysis

IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, NY, USA) was used for the statistical analysis. One-way analysis of variance with Dunnett's T3 test was performed on the marginal gap data, and Bonferroni's test was used for the tensile test. The significance level was set at $P = 0.05$.

Results

The marginal fit results for each study group are shown in Fig. 5. The framework design significantly affected marginal fit. The marginal gaps for the inlay-, L-, and D-shaped RBFDPs were 59.8 ± 7.5, 63.5 ± 6.1, and 110.2 ± 16.8 μm, respectively. The D-shaped RBFDP showed a significantly greater marginal gap than the inlay- and L-shaped RBFDPs ($P < 0.05$). Furthermore, within each group, there were no obviously large values among the measurement points in the inlay- and L-shaped RBFDPs, whereas in the D-shaped RBFDP, the marginal gap around the cusps tended to be

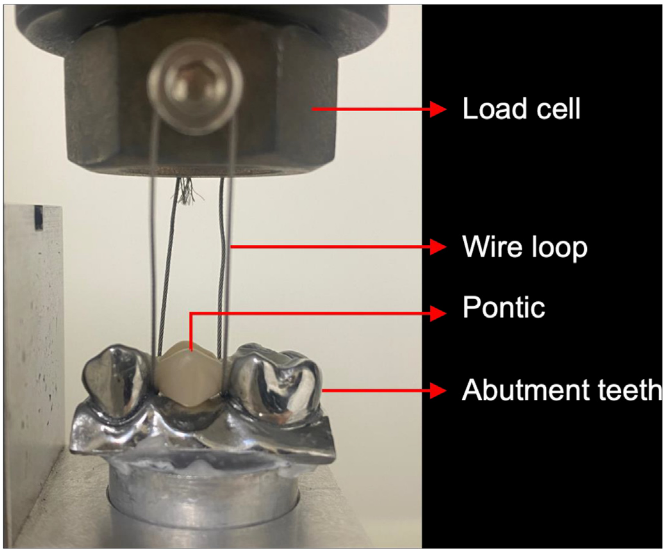

Figure 4 Tensile test view. The abutment tooth with the RBFDPs were mounted on a universal testing machine and connected to a load cell with a wire loop to perform a tensile test. Wire loop was passed through both tissue sides of the pontic.

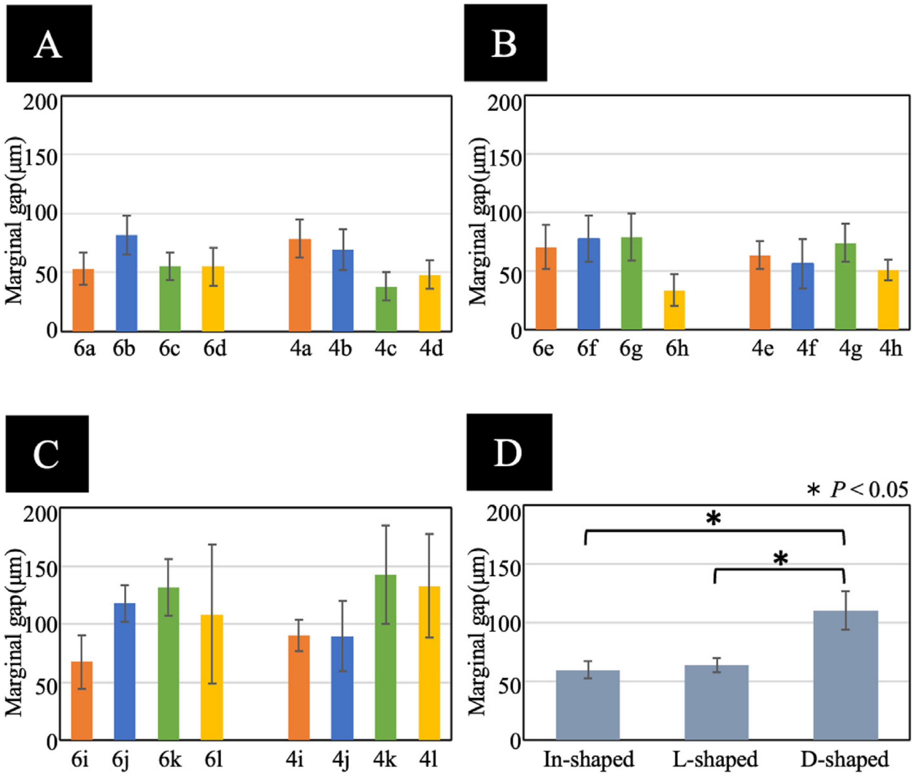

Figure 5 Results of the marginal gap of study groups. Data were presented as the mean ± standard deviation. * indicates a significant difference. (A) Inlay-shaped resin-bonded fixed dental prostheses (RBFDPs), (B) L-shaped RBFDPs, (C) D-shaped RBFDPs, (D) Comparison of 8-point combined averages.

particularly larger, especially the k-point showed an average value of 137.5 μm.

In the tensile test, the inlay- and L-shaped RBFDPs exhibited an average tensile strength of 221.8 ± 118.0 and 156.4 ± 85.8 N, respectively, whereas the D-shaped showed a maximum tensile strength of 433.8 ± 230.1 N, which is significantly greater than that of the inlay- and L-shaped RBFDPs ($P < 0.05$) (Fig. 6).

After the tensile tests, the surfaces of the framework and abutment teeth were observed using SEM. All inlay-shaped RBFDPs showed debonding from the abutment tooth with cohesive failure in the cement layer, which is thought to be a repairable failure pattern in clinical practice. In the L-shaped configuration, eight out of ten exhibited a fracture at the retainer wing near the connector. In the D-shaped RBFDPs, debonding occurred in nine specimens, and the remaining showed a fracture in the premolar. Except for the fractured one, most of the frameworks (8/9) exhibited cohesive failure in the cement layer (Fig. 7). Scanning electron microscopy images of frameworks after tensile test are shown in Fig. 8. Cohesive failure interface was observed in all the inlay-shaped frameworks (a, d) and

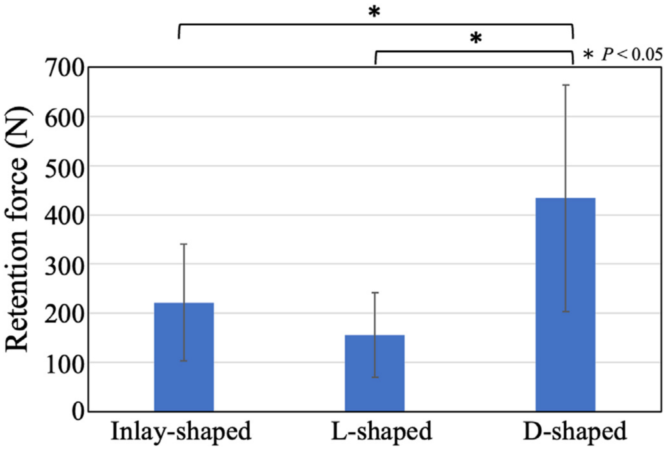

Figure 6 Retention force of resin-bonded fixed dental prostheses after the aging test. * indicates a significant difference.

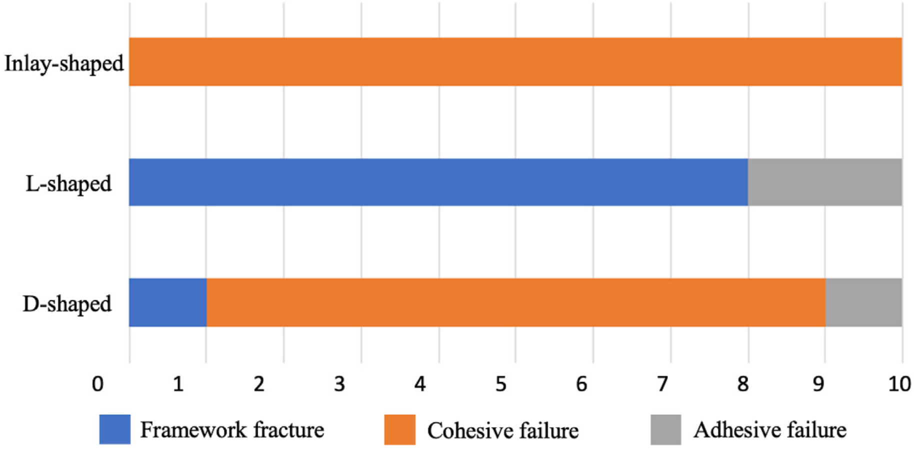

Figure 7 The number of failure modes after tensile test is shown above. The failure modes were classified into 3 types. Framework fracture, Cohesive failure and Adhesive failure.

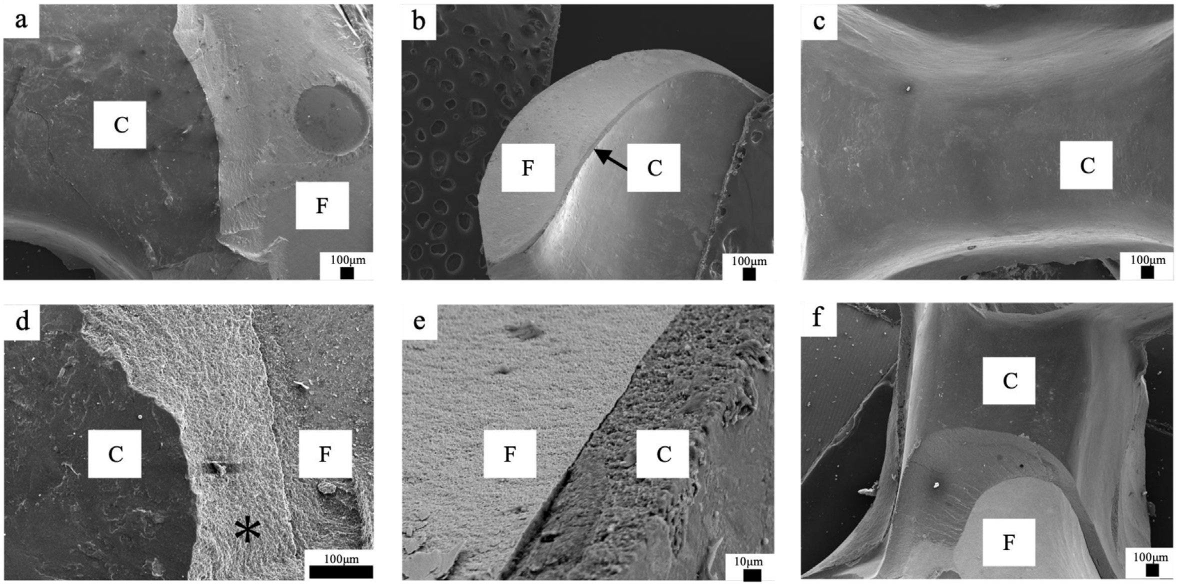

Figure 8 Scanning electron microscopy images of frameworks after tensile test. (a, d) Cohesive failure of Inlay-shaped framework, (b, e) Fracture surface of L-shaped framework, (c) Adhesive failure of D-shaped framework, (f) Cohesive failure of D-shaped framework F; framework, C; cement, *; cohesive failure of cement.

some of the D-shaped frameworks (f). In addition, Fig. 8b and e showed the fracture surface of L-shaped. Fig. 8c was the only adhesive failure in D-shaped frameworks.

Discussion

This in vitro study aimed to evaluate the marginal fit of zirconia RBFDPs with different designs in the posterior region and assess the effect of the framework design on the retention force. According to the results, the first null hypothesis, which stated that framework designs do not affect the marginal discrepancy, was rejected as the D-shaped marginal gap was significantly greater than the inlay- and L-shaped gaps. Moreover, the retention force was significantly higher for the D-shaped RBFDP than for the inlay- and L-shaped RBFDPs. Thus, the second null hypothesis that the framework design has no effect on the retention force was also rejected.

Marginal fitness has been implicated in the prevention of secondary caries and periodontal diseases.[24,25] Thus, evaluating the prosthetic marginal fit is essential before assessing its clinical application potential. In this study, the marginal gap was 110.2 ± 16.8 μm for D-shaped RBFDPs. A systematic review to analyze dental zirconia prosthesis with multiple units showed the marginal fitness ranged from 48 to 141 μm,[26] which indicates the D-shaped retainer can be acceptable for clinical use. However, the marginal gap of D-shaped RBFDPs is approximately twice larger than that of inlay- and L-shaped RBFDPs, especially in the hole area, with the worst fitness showing a value of 198 μm. The poor marginal fitness compared to the inlay- and L-shaped retainers could perhaps have been hypothesized that the D-shaped retainer consists of internal and external cavities. These complex structures could cause difficulties in regulating the shrinkage of zirconia during the sintering procedure. So, the optimal teeth preparation and design of the retainer should be further investigated.

Zirconia RBFDPs with diverse designs have a high load-bearing capacity in the posterior region.[21,27] Nevertheless, from a clinical perspective, debonding occurs more frequently than fractures.[28] The debonding mechanism is attributed to deformation of the framework when functional forces are applied to the restoration, which causes a peeling force at the bonding interface.[29] Zirconia has high bending strength and elastic modulus and is less prone to distortion, making it more difficult to debond than dental alloys.[30] However, the stress concentration varies according to the retainer design, which may cause differences in debonding rate.

The D-shaped sample exhibited the highest retention force. In this study, the D-shape was the ideal design that could resist debonding in the posterior region. This is consistent with a previous study that stated that the D-shaped retainer provided a more even stress distribution for resin-bonded prostheses than the traditional L-shaped retainer.[31] The same trend was observed in an in vitro study by Chen et al.[13] who certified D-shaped and recommended retainer designs for clinical practice.

By contrast, the L-shaped framework exhibited the lowest retention force, and most of the frameworks had fractures close to the molar connectors. Previous finite element analysis studies have shown that stresses tend to be concentrated in connectors.[31,32] During dynamic loading, the stress concentration near the connector caused deformation of the framework, thereby collapsing the cement layer and microcracks. Consequently, in the subsequent tensile test, the retainer fractured near the connector, and the adhesive area decreased, which may have led to debonding. However, other studies on posterior zirconia retainer designs suggest that a modified design (occlusal rest and two retainer wings) exhibits promising durability and retention.[19] In another study, Ammar et al.[32] stated that the L-shaped was below the normal occlusal force and should be used carefully. Therefore, future studies should consider a two-wing L-shaped design.

In this study, thermal cycling and repetitive loading were performed on the specimen to reproduce the intraoral environment. In the oral cavity, temperature changes and mastication would degrade the adhesion between the restored and abutment teeth. Moreover, 6000 times of thermal cycle and 240,000 cycles of repetitive loading were applied for mastication simulations for 1 year.[23] The loading point was set at the center of the pontic tooth. This is not a typical occlusal contact area because applying loads directly to the pontic area is not advised in clinical practice. The worst-case scenario was considered in this study. Consequently, obvious fractures or debonding of framework were not observed during this process.

To verify the clinical application of zirconia RBFDP in the posterior region, their various physical properties must be evaluated. In this study, we evaluated fit accuracy and retentive force using marginal discrepancy and tension tests, which would be clinically beneficial because it would help select an appropriate zirconia RBFDPs design, which may improve the prognosis of restorations.

The limitation of this study is that the fracture pattern and stress transfer to the natural teeth cannot be analyzed because a Co—Cr dental alloy was used for the abutment teeth. There are several solutions to overcome the discrepancies between the in vitro test and the clinical situation. One is to use the FEA studies which enable us to estimate the stress distribution in the clinical situation because the model includes the true mechanical properties and structure of organs and materials. The other is to establish the in vitro test method to mimic the mechanical properties and structure. A recent study reveals that the in vitro tooth model with periodontal ligament reduces the wear of the prosthesis compared to the model without periodontal ligament, which indicates that the results from the in vitro tooth model without periodontal ligament are more intense compared to that with periodontal ligament.[33] So, our study model should be done under severe conditions compared to the clinical situation.

In this study, we fabricated three types of retainers—inlay-, L-, and D-shaped type—for RBFPDs and found that their marginal fitness was acceptable for clinical use. To inhibit debonding of the RBFPDs from the abutment teeth, a D-shaped retainer is highly recommended because it has the greatest retention force compared with inlay- and L-shaped retainers. However, because of the relatively poor accuracy of fit in the D-shaped group, long-term clinical studies are required before these restorations can be recommended for general clinical use.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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References

1. Pjetursson BE, Sailer I, Makarov NA, Zwahlen M, Thoma DS. All-ceramic or metal-ceramic tooth-supported fixed dental prostheses (FDPs)? A systematic review of the survival and complication rates. Part II: multiple-unit FDPs. *Dent Mater* 2015;31:624—39.
2. Pjetursson BE, Brägger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). *Clin Oral Implants Res* 2007;18:97—113.
3. Matta RE, Eitner S, Stelzer SP, Reich S, Wichmann M, Berger L. Ten-year clinical performance of zirconia posterior fixed partial dentures. *J Oral Rehabil* 2022;49:71—80.
4. Lieban EA. Pulpal irritation and devitalization as a result of preparation of teeth for complete crowns. *J Am Dent Assoc* 1955;51:679—84.

5. Jackson CR, Skidmore AE, Rice RT. Pulpal evaluation of teeth restored with fixed prostheses. *J Prosthet Dent* 1992;67:323—5.
6. Yoshida T, Kurosaki Y, Mine A, et al. Fifteen-year survival of resin-bonded vs full-coverage fixed dental prostheses. *J Prosthodont Res* 2019;63:374—82.
7. Alraheam IA, Ngoc CN, Wiesen CA, Donovan TE. Five-year success rate of resin-bonded fixed partial dentures: a systematic review. *J Esthetic Restor Dent* 2019;31:40—50.
8. Pjetursson BE, Lang NP. Prosthetic treatment planning on the basis of scientific evidence. *J Oral Rehabil* 2008;35:72—9.
9. Thoma DS, Sailer I, Ioannidis A, Zwahlen M, Makarov N, Pjetursson BE. A systematic review of the survival and complication rates of resin-bonded fixed dental prostheses after a mean observation period of at least 5 years. *Clin Oral Implants Res* 2017;28:1421—32.
10. Kerschbaum T, Haastert B, Marinello CP. Risk of debonding in three-unit resin-bonded fixed partial dentures. *J Prosthet Dent* 1996;75:248—53.
11. Botelho MG, Dyson JE, Mui THF, Lam WYH. Clinical audit of posterior three-unit fixed-movable resin-bonded fixed partial dentures - a retrospective, preliminary clinical investigation. *J Dent* 2017;57:26—31.
12. Chen J, Cai H, Ren X, Suo L, Pei X, Wan Q. A Systematic review of the survival and complication rates of all-ceramic resin-bonded fixed dental prostheses. *J Prosthodont* 2018;27:535—43.
13. Chen X, Zhang Y, Zhou J, Chen C, Zhu Z, Li L. Effect of different surface treatments and retainer designs on the retention of posterior Pd-Ag porcelain-fused-to-metal resin-bonded fixed partial dentures. *Exp Ther Med* 2018;15:2006—14.
14. Doh RM, Lee KW. Dislodgement resistance of modified resin-bonded fixed partial dentures utilizing tooth undercuts: an in vitro study. *J Adv Prosthodont* 2009;1:85—90.
15. Zhang Y, Lawn BR. Evaluating dental zirconia. *Dent Mater* 2019;35:15—23.
16. Bömicke W, Karl J, Rammelsberg P. Minimally invasive prosthetic restoration of posterior tooth loss with resin-bonded, wing-retained, and inlay-retained fixed dental prostheses fabricated from monolithic zirconia: a clinical report of two patients. *J Prosthet Dent* 2017;117:459—62.
17. Rathmann F, Bömicke W, Rammelsberg P, Ohlmann B. Veneered zirconia inlay-retained fixed dental prostheses: 10-Year results from a prospective clinical study. *J Dent* 2017;64:68—72.
18. Chaar MS, Kern M. Five-year clinical outcome of posterior zirconia ceramic inlay-retained FDPs with a modified design. *J Dent* 2015;43:1411—5.
19. Tagami A, Chaar MS, Wille S, Tagami J, Kern M. Retention of posterior resin bonded fixed dental prostheses with different designs after chewing simulation. *J Mech Behav Biomed Mater* 2021;123:104758.
20. Kiliçarslan MA, Kedici PS, Küçükeşmen HC, Uludağ BC. In vitro fracture resistance of posterior metal-ceramic and all-ceramic inlay-retained resin-bonded fixed partial dentures. *J Prosthet Dent* 2004;92:365—70.
21. Kasem AT, Elsherbiny AA, Abo-Madina M, Tribst JPM, Al-Zordk W. Biomechanical behavior of posterior metal-free cantilever fixed dental prostheses: effect of material and retainer design. *Clin Oral Invest* 2023;27:2109—23.
22. Kitani J, Komine F, Kusaba K, Nakase D, Ito K, Matsumura H. Effect of firing procedures and layering thickness of porcelain on internal adaptation of zirconia cantilever resin-bonded fixed dental prostheses. *J Prosthodont Res* 2022;66:333—8.
23. Kern M, Strub JR, Lü XY. Wear of composite resin veneering materials in a dual-axis chewing simulator. *J Oral Rehabil* 1999;26:372—8.
24. Srimaneepong V, Heboyan A, Zafar MS, et al. Fixed prosthetic restorations and periodontal health: a narrative review. *J Funct Biomater* 2022;13:15.
25. Larson TD. The clinical significance of marginal fit. *NW Dent* 2012;91:22—9.
26. Svanborg P. A systematic review on the accuracy of zirconia crowns and fixed dental prostheses. *Biomater Investig Dent* 2020;7:9—15.
27. Kasem AT, Abo-Madina M, Tribst JPM, Al-Zordk W. Cantilever resin-bonded fixed dental prosthesis to substitute a single premolar: impact of retainer design and ceramic material after dynamic loading. *J Prosthodont Res* 2023;67:595—602.
28. Zitzmann NU, Büren A von, Glenz F, Rohr N, Joda T, Zaugg LK. Clinical outcome of metal- and all-ceramic resin-bonded fixed dental prostheses. *J Prosthodont Res* 2021;65:243—8.
29. Boyer DB, Williams VD, Thayer KE, Denehy GE, Diaz-Arnold AM. Analysis of debond rates of resin-bonded prostheses. *J Dent Res* 1993;72:1244—8.
30. López-López E, Erauw JP, Moreno R, Cambier F, Baudín C. Elastic behaviour of zirconium titanate-zirconia bulk composite materials at room and high temperature. *J Eur Ceram* 2013;33:3195—200.
31. Lin J, Zheng Z, Shinya A, Matinlinna JP, Botelho MG, Shinya A. Structural stability of posterior retainer design for resin-bonded prostheses: a 3D finite element study. *Odontology* 2015;103:333—8.
32. Kasem AT, Elsherbiny AA, Abo-Madina M, Tribst JPM, Al-Zordk W. Effect of different designs of minimally invasive cantilever resin-bonded fixed dental prostheses replacing mandibular premolar: long-term fracture load and 3D finite element analysis. *J Prosthodont* 2023;32:e41—51.
33. Kosewski P, De Angelis F, Sorrentino E, Mielczarek A, Buonvivere M, D'Arcangelo C. Effect of the abutment rigidity on the wear resistance of a lithium disilicate glass ceramic: an in vitro study. *J Funct Biomater* 2023;14:395.