Fracture resistance of direct inlay-retained adhesive bridges: Effect of pontic material and occlusal morphology

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INTRODUCTION

With the developments in the field of reinforced polymers, the use of pre-impregnated fiber-reinforced composites (FRC) has increased in dentistry. Today, FRCs are usually indicated for periodontal or traumatic splinting, as endodontic posts, for intraoral repair of metal-ceramic crowns16, for reinforcement of direct or indirect fixed dental prostheses (FDP)17, and in orthodontics for fixed retainers18. Various types of fibers such as glass fiber3, polyester fiber5, carbon/graphite fiber3, aramid (Kevlar) fiber3 and ultra high molecular weight polyethylene fiber (UHMWPE)9 are added into the composite materials in order to improve mechanical properties. The amount of fibers in the matrix, diameter and length of fibers10, fiber form10, adhesion of fibers to the polymer matrix10, water sorption of FRC matrix15, location, orientation15 and impregnation of fibers12 influence the mechanical properties of FRCs.

FRCs have suitable flexural modulus and flexural strength for functioning successfully in the mouth as a restorative material14. The average masticatory forces are reported to range between 155 and 222 N for anterior and up to 830 N for posterior teeth15.15. In a previous in-vitro study, it was reported that FRC application increased the fracture load of resin crowns to the level of intact crowns16. In another study, fracture strength of FRC FDPs exceeded the reported highest masticatory force values of 1000 N15. For that reason, such restorations are considered strong enough for clinical applications17. Certainly, adhesion to dental tissues and other restorative materials using adhesive promoters increased their potential indications18.

Among all other applications, inlay-retained FRC FDPs are considered as alternative therapy options to conventional full-coverage FDPs, resin-bonded FRCs and implants. Inlay-retained FRC FDPs can be made directly in the mouth or indirectly in the laboratory. The indirect technique is time consuming and more expensive than the direct application due to the laboratory procedures. Moreover, limited clinical information on their survival is unfortunately not promising19-22. On the other hand, adhesion of resin-based materials to enamel and dentin is superior in direct application since these restorations do not require temporization that eventually eliminates contamination on the enamel and/or dentin17. The limiting factors of chair-side direct FRC FDP applications is that their quality highly depends on the operator’s clinical skills during establishing the anatomical form of the pontic. With the use of prefabricated pontics, the application of FRC FDPs for replacement of missing teeth may be simplified and perhaps increase their indications23. For this purpose, extracted teeth24, acrylic resin denture teeth25 and porcelain denture teeth can be used as pontic materials for direct FRC FDPs. Various occlusion concepts have been developed in dentistry over the years with the claim that they significantly influence the technical complications of FDPs26-28. Such pontic materials present different occlusal morphologies and free-hand constructed ones of course vary in each case. It can be anticipated that with the increase in surface area, increased chewing forces could be expected on the pontics. In addition, deep cusp morphologies may be more prone to wedgeing effect. Limited information is available on the effect of pontic types for FRC FDPs29-31 and to the authors’ best knowledge the effect of occlusal...
morphologies is unknown.

The objectives of this study therefore were to evaluate the effect of different pontic materials and occlusal morphologies on the fracture resistance of FRC FDPs. The hypothesis tested were that different pontic materials would not, but variations in occlusal morphologies would affect the fracture resistance of FRC FDPs.

**MATERIALS AND METHODS**

*Specimen preparation - pontic type effect*

For this part of the study, human mandibular first premolars \( n=45 \) and first molars \( n=45 \) with similar sizes, free of restorations and root canal treatment were selected from a pool of recently extracted teeth. According to the guidelines of the ethical commission of the Dental School, all patients were informed that their extracted teeth may be used for experimental purposes. The teeth were cleaned of any remaining soft tissue and calculus and paired randomly. Each pair of premolar and molar \((n_{	ext{pair}}=9)\) was embedded in auto-polymerized polymethyl methacrylate (PMMA) (Autoplast, Candulor AG, Wangen, Switzerland). The teeth were aligned with the help of a parallelometer during the embedding process in the mold while pouring the PMMA. A distance of \( 7 \pm 0.2 \) mm was established between the two abutment teeth to achieve space for a missing second premolar (tooth no. 45). The PMMA was polymerized at 2 bars in a high-pressure device (Duna Dental, Bösingen, Germany) in water at 55ºC for 15 min. All pairs were dried with an air syringe.

Firstly, the mesio-distal (molar: \( 3.9 \pm 0.2 \) mm; premolar: \( 2.7 \pm 0.2 \) mm) and occlusocervical dimensions (molar: \( 3.2 \pm 0.2 \) mm; premolar: \( 2.9 \pm 0.2 \) mm) of the inlay boxes were indicated with a water stable pen after measuring with a digital micrometer (accurate to 0.005 m) (Mitutoyo Ltd., Andover, UK) (Fig. 1). Inlay boxes on the distal surface of premolars and the mesial surface of molars, with margins in enamel, at least 1 mm above the cemento-enamel junction, were prepared by one operator using conventional fine diamond inlay burs (model number 011, Cerinlay; Intensiv, Grancia, Switzerland) with a high-speed handpiece (KaVo K9, handpiece type 950; KaVo, Biberach, Germany) utilizing water spray. A new set of burs was used after every 9 preparations. The bucco-lingual dimensions and bevelling were standardized using the ultrasonic tips (no.3, SONICSYS approx. micro torpedo; KaVo) for the premolars and the molars. The linear oscillation speed was 6.5 kHz. The preparations were cleaned with water spray for 15 s and dried with an air syringe.

Prior to restoring missing teeth, a preformed wax sheet (thickness: 2 mm) (Modelling Wax, Gebdi Dental Products, Engen, Germany) was placed between the abutment teeth to act as an index in order to create identical shape and form of the cervical aspect of the pontic. The pontics had buccolingual width of 7 mm and cervicoocclusal height of 6 mm.

Enamel and dentin were etched with 38% phosphoric acid (TopDent Gel, TopDent, Vasteras, Sweden) for 15 s and gently air-dried. The dentin surface was conditioned with primer (Quadrant Unibond Primer, Cavex, Haarlem, The Netherlands) for 15 s and then air-dried. The adhesive resin (Quadrant Unibond Sealer, Cavex) was applied to enamel and dentin, and after the excess was gently airblown, it was photo-polymerized (Optilux 501, Kerr, West Collins Orange, CA) for 10 s.

Depending on the experimental group, different techniques were used to place the E-glass FRC (EverStick C&B, Sticktech, Turku, Finland) and create the pontic. The E-glass FRC used was a readily silanized and pre-impregnated one with Bis-GMA and PMMA. The dimensions of the pontics are presented in Table 1.

Four different pontic materials were used to restore the missing teeth (#45) as follows (Figs. 2a–e):

**Group a:** In this group, pontic was built up using a photo-polymerized resin composite (Clearfil Photo Posterior, Kuraray, Tokyo, Japan) and this group served as the control group. First, the distance between the cavities was measured using a digital calliper and the E-glass FRC bundle was cut with the same dimensions measured. Then a low viscosity resin composite (Tetric Flow, Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the gingival and axial walls covering one third of the box. The FRC bundle was carefully positioned into the cavities in the bed of the flowable resin. At the gingival (tension) side of the FDP, it was slightly curved cervical in the middle of the pontic and photo-polymerized for 40 s. Then adhesive resin (StickResin, StickTech) was applied to the entire surface of the FRC to be bonded and it was photo-polymerized for 10 s. Following the bonding procedures, the resin composite (Clearfil Photo Posterior, Kuraray) was contoured and bonded to the conditioned surfaces and each layer was photo-polymerized for 40 s.

**Group b:** Extracted human premolars were used as pontic materials. A groove was prepared (2 mm×2
Table 1  Mean dimensions of natural teeth, acrylic and porcelain denture teeth, resin composite pontics

<table>
<thead>
<tr>
<th>Pontic Dimensions</th>
<th>Width (mm)</th>
<th>Cervico-occlusal height (mm)</th>
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<tbody>
<tr>
<td>Buccolingual</td>
<td>7.9±0.6</td>
<td>6.4±0.7</td>
</tr>
<tr>
<td>Mesial</td>
<td>4.7±0.3</td>
<td>3.9±0.2</td>
</tr>
<tr>
<td>Distal</td>
<td>4.8±0.3</td>
<td>3.9±0.2</td>
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Fig. 2 Photos of different pontic materials a) resin composite (deep anatomy), b) natural tooth, c) acrylic denture tooth, d) porcelain denture tooth and e) resin composite (shallow anatomy) from occlusal view.

Fig. 3 Photos of a) the groove on the gingival side of the acrylic denture tooth (width: 2 mm, depth: 2 mm), b) FRC bundle in the bed of the flowable resin at the gingival aspect, c) FRC bundle in the groove from the occlusal aspect.

mm) mesio-distally on the occlusal surfaces of the extracted teeth, and the tooth conditioning procedures were performed as described in Group a. Thereafter, flowable resin (Tetric Flow, Ivoclar Vivadent) composite was applied into the cavities of the abutment teeth and into the groove of the extracted natural tooth. Previously measured FRC bundle was carefully positioned along the cavities of the abutment teeth and the groove of the pontic, and photo-polymerized for 40 s. Then, adhesive resin (StickResin, StickTech) was applied to the entire surface of the FRC and it was photo-polymerized for 10 s. The cavities and the groove on the pontic was filled with the resin composite.

In Groups c and d, acrylic (SR-Antaris, Ivoclar Vivadent) and porcelain denture teeth (Enta Acrylic Teeth, Enta B.V., Bergen op Zoom, Netherlands) were used as pontic materials, respectively. Tooth preparations were made as in Group a. Grooves were opened on the gingival surfaces of the pontics to create space for the FRC bundle as described in Group b (Figs. 3a–c).
Fig. 4  Representative photos of an FDP with acrylic denture tooth a) the embedded teeth acting as the abutments, b) trying the denture tooth in the pontic space, c) FRC bundle at the gingival side of the denture tooth, d) FRC FDP in situ from the occlusal aspect.

Fig. 5  Photo of a representative FDP and loading direction onto the pontic with the loading sphere (5 mm in diameter) during fracture resistance test.

Groove areas on denture tooth surfaces were conditioned using silica coating (CodJet®-Sand, 3M ESPE AG, Seefeld, Germany) for 30 s and silanized (ESPE®-Sil, 3 M ESPE AG) for 5 min. Then, an adhesive resin (StickResin, StickTech) was applied, air thinned and without photo-polymerization filled with flowable resin (Tetric Flow, Ivoclar Vivadent). The pontic with the FRC bundle in the groove was placed in position (Figs. 4a–d). The excess was removed using microbrushes and a dental probe.

Group e: An additional group was created identical to Group a to test whether location of the loading point affects the fracture resistance of FRC FDPs. While load was exerted on the mesial and distal marginal ridges with the steel sphere in Group e having a shallow anatomy, the steel sphere was in contact with the buccal and lingual cusp tips in Group a having a deep anatomy (Fig. 5). In Group a the distance between the highest point of the buccal cusp and the fissure was 3.5 mm and in Group e it was 2 mm.

The bonded FRC FDP was photo-polymerized for 40 s per side. Finally, finishing and polishing procedures were performed using silicone brushes (Astropol, Ivoclar Vivadent).

Fracture resistance test
The samples were positioned in the jig of the universal testing machine (Z2.5/TS1S, Zwick/Roell Nederland, Venlo, The Netherlands) at a constant speed of 1 mm/min until fracture occurred. The force (N) was applied from the occlusal direction to the central fossa with a steel loading sphere, 5 mm in diameter that started moving from a distance of 2 mm from the occlusal surface (Fig. 5). The initial distance of 2 mm served for easy access to position the specimen under the loading sphere easier. The loading sphere was later positioned 1 mm above the specimen.

Specimen preparation - occlusal morphology effect
To test the effect of occlusal morphology on the fracture resistance, three aluminium beams (15 mm×7 mm×4 mm) with different surface shapes and contact points in relation to the loading sphere were prepared and replicated in resin composite (Clearfill Photo Posterior, Kuraray) (N=30, n=10 per group): i) ‘circular’ (5 mm in diameter, ≈1.34 mm in depth, perfectly fitting the testing ball), ii) ‘elliptic I’ (4 mm in diameter bucco-lingually, with a contact point in mesio-distal direction with the loading sphere), and iii) ‘elliptic II’ (4 mm in diameter mesio-distally, with a contact point in bucco-lingual direction with the loading sphere) (Table 2, Figs. 6a–c). To establish the surface forms on the aluminium beams in group i, a round bur with an outer diameter of 6 mm was used. The second and third aluminium beams were produced with the aid of a custom made spherical metals to decrease the inner diameter from 5 to 4 mm either mesio-distally or bucco-lingually. Negative reproductions of the aluminium beams were made using silicon impression material (President, Coltene Whaledent, Langenau, Germany). The silicon material was surrounded by hard plastic material to prevent the flow of the material.

Resin composite material (Clearfill Photo Posterior, Kuraray) was preheated at 35°C to increase the flow and prevent air bubbles before placed in the mould. One layer of composite was placed in the mould and covered with a glass plate. The exposed surfaces of the composite specimens were photo-polymerized for 120 s from a
Fig. 6 Photos of the aluminium beams and the composite specimens produced from the silicone replicas of these beams (length: 15 mm, width: 7 mm, thickness: 4 mm) representing occlusal surfaces of the pontics with different occlusal morphologies a) ‘circular’ \( r=5 \text{ mm in vertical and } r=5 \text{ mm in horizontal direction}, \approx 1.34 \text{ mm in depth} \), b) ‘elliptic I’ \( r=4 \text{ mm in vertical and } r=5 \text{ mm in horizontal direction}, \approx 1.34 \text{ mm in depth} \), c) ‘elliptic II’ \( r=5 \text{ mm in vertical and } r=4 \text{ mm in horizontal direction}, \approx 1.34 \text{ mm in depth} \) in relation to the loading sphere. The loading sphere used was the same as presented in Fig. 4.

<table>
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<tr>
<th>Dimensions and Contact Points</th>
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<tr>
<td>Diameter</td>
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<tr>
<td>Group (i) ‘Circular’</td>
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<tr>
<td>Group (ii) ‘Elliptic I’</td>
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<tr>
<td>Group (iii) ‘Elliptic II’</td>
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distance of 2 mm. They were then removed from the moulds and the bottom parts of the composite specimens were further photo-polymerized for another 120 s. Prior to the fracture test, the specimens were stored in dry conditions at room temperature for 1 week.

An additional custom-made stainless steel holder was prepared to stabilize and standardize the position of the composite beams during the fracture test. Every specimen was placed in the middle of the custom-made holder that allowed 4 mm of support on each side of the resin specimen and the remaining 7 mm portion of the resin block was left unsupported in the universal testing machine (Z2.5/TS1S, Zwick/Roell). The distance between the two supporting points was 7 mm. The resin block was secured in a metal holding jig with screws in position from both sides prior to testing. The loading sphere (diameter: 5 mm) was manually directed in position 1 mm above the composite beam. Load was applied at a constant speed of 1 mm/min until fracture occurred.

Statistical analysis
Statistical analysis was performed using SPSS System 15.0 for Windows (SPSS Inc., Chicago, IL, USA). The means of each group were analyzed by one-way analysis of variance (ANOVA). Due to significant differences between groups for both the first and second parts of the study, multiple comparisons were made by Tukey’s adjustment test. \( P \) values less than 0.05 were considered to be statistically significant in all tests.

RESULTS
There was no statistically significant differences between the fracture strength of Groups a, b, c, and d (598, 543,
Table 3 The mean fracture resistance (N) and standard deviations of the inlay-retained FRC FDPs with different pontic materials: a) resin composite with deep anatomy, b) natural tooth, c) acrylic denture tooth, d) porcelain denture tooth, e) resin composite with shallow anatomy and resin composite specimens representing occlusal surfaces of the pontics with different morphologies: i) ‘circular’, ii) ‘elliptic I’, iii) ‘elliptic II’.

<table>
<thead>
<tr>
<th>Group</th>
<th>Fracture Resistance (N)</th>
<th>Standard Deviation</th>
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<tr>
<td>a: Resin composite with deep anatomy</td>
<td>598</td>
<td>240</td>
</tr>
<tr>
<td>b: Natural tooth</td>
<td>543</td>
<td>162</td>
</tr>
<tr>
<td>c: Acrylic denture tooth</td>
<td>539</td>
<td>301</td>
</tr>
<tr>
<td>d: Porcelain denture tooth</td>
<td>509</td>
<td>151</td>
</tr>
<tr>
<td>e: Resin composite with shallow anatomy</td>
<td>1,186</td>
<td>224</td>
</tr>
<tr>
<td>i: ‘Circular’</td>
<td>1,750</td>
<td>198</td>
</tr>
<tr>
<td>ii: ‘Elliptic I’</td>
<td>1,790</td>
<td>254</td>
</tr>
<tr>
<td>iii: ‘Elliptic II’</td>
<td>871</td>
<td>123</td>
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Fig. 7 The mean fracture resistance and standard deviations of the inlay-retained FRC FDPs with different pontic materials: a) resin composite with deep anatomy, b) natural tooth, c) acrylic denture tooth, d) porcelain denture tooth, e) resin composite with shallow anatomy.

Fig. 8 The mean fracture resistance and standard deviations of resin composite specimens representing occlusal surfaces of the pontics with different morphologies: i) ‘circular’, ii) ‘elliptic I’, iii) ‘elliptic II’. See Table 2 for group descriptions.

539, 509 N, respectively (p>0.05). Fracture strength of Group e (1,186 N) was significantly higher than those of other groups (p<0.05) (Fig. 7, Table 3). In none of the specimens fiber fractures were observed. Failure type was exclusively in the pontic material.

While Group iii (871 N) showed significantly lower fracture strength values than those of the other groups (p<0.05), no significant difference was found between Group i (1,750 N) and Group ii (1,790 N) (Fig. 8).


**DISCUSSION**

Fracture phenomenon in restorative materials is one of the greatest concerns in dentistry. This study was undertaken in order to evaluate the effect of pontic material and occlusal morphology on the fracture resistance of inlay-retained FRC FDPs and resin composite blocks. In the first part of the study, no significant difference was found between the pontic materials except one group where resin composite pontic had a shallow occlusal anatomy. This group showed significantly the highest mean fracture resistance. Thus, the first hypothesis could be partially accepted. Although the pontic materials tested have marked different mechanical properties, non-significant difference between Groups a, b, c, d and the exclusive failures only in the pontic material indicates that the adhesion of the FRC and the resin composite to the tooth material was superior compared to their adhesion to the pontic material. Eventually, delamination between the FRC bundle and the pontic was experienced instead of delamination from the box preparations.

The clinical performance of FRC FDPs in dental applications depends not only on their physical properties, but also on the handling characteristics of these materials and the clinical skills of the operator[^30]. Since the resin composite pontics are built-up free hand under rubber dam, morphological features of these pontics may vary. In this study, mean fracture resistance of the FRC FDPs with pontics having shallow anatomy (Group a) presented significantly lower results compared to those with deeper anatomy (Group e). In Group a, the loading sphere exerted pressure primarily on the buccal and lingual cusps of the pontic which possibly yielded to a kind of wedging effect between the cusps. When the pontics are loaded on the cusp tips initially shear forces take place. This is then accompanied by tensile stresses in the bulk of the pontic material and ultimately the cervical area of the pontic contributes to the cohesive fracture of the pontic[^30].

When the veneering composite at the cusp area breaks earlier than the whole construction, this indicates that the cohesive strength of the material is less than the FRC-pontic adhesion. In such a situation from the reinforcement effect of the FRC could be profited. In both Groups a and e, cusp tips of the abutment teeth were considered as reference points. The inclination of the cusp tip in Group a (buccal cusp tip-fissure distance 3.5 mm), towards the main fissure was created less deeper than in Group e (buccal cusp tip-fissure distance 2 mm).

Failures in clinical or in-vitro studies seldom mentioned FRC fracture but reported more often separation of the veneering composite from the FRC surface[^13,16,17]. The occlusal anatomy could be one of the reasons for such failures, which requires closer attention in clinical studies in the future. Perhaps a more flat contact point on the buccal and lingual cusp tips may increase the survival rate.

Inlay-retained FRC FDPs should be ideally reinforced at the gingival side of the pontic because the tensile stresses are the highest in this region[^31]. In this study, grooves were opened at the gingival sites of the denture teeth but at the occlusal side of the natural teeth pontics. Acrylic and porcelain denture teeth presented similar occlusal morphologies whereas the natural teeth showed different occlusal morphologies although anatomically similar teeth were selected. When the natural teeth were decapitated, the location of the pulp chamber did not always allow standard groove preparation. For this reason, in this group, grooves were opened at the occlusal side. Interestingly, no significant difference was found between the fracture resistances of the FRC FDPs when different pontics were used and when even the fiber bundle was placed either at the compressive or tensile sides of the pontics. Possibly, the good adhesion of the fiber and the resin composite onto enamel and dentin exceeded that of the cohesive strength of the pontic material and thereby no debonding but only fractures in the pontic materials were observed. Nevertheless, the location of the fiber bundle in high reconstructions requires further investigations. Among other factors such as pontic type and even the fiber location, the loading point seems to have a dominant effect on the fracture resistance of the whole FRC FDPs. From the clinical point of view, it can be stated that while adjusting the occlusion, no deep fissures should be created.

In the second part of this study, when the loading sphere applied force in the bucco-lingual direction on the resin composite block, significantly lower results were obtained. Since occlusal morphologies presented an effect on the overall resistance of composites, the second hypothesis could be accepted. This finding indicates that while loading in bucco-lingual direction causes early fracture of the composite, forces applied in the mesio-distal direction or in the middle of the occlusal curvature may dissipate the forces and reduces stresses in the volume of the composite. In a study that focused on the stress analysis of all-ceramic FDPs, it has been shown that the number and the location of contact points influence the induced stresses[^32]. In another study that focused on the stress distribution on the tooth-implant supported FDPs, it was reported that the loading condition is the main factor affecting stress distribution on the prosthetic components[^33]. Similarly, occlusal contact points affected the results in the resin composite tested in this study. The results of the present study indicate that while adjusting the occlusion, the occlusal contact points should be created on the mesial and distal sides of the occlusal surface of the pontic in order to increase the fracture resistance of an inlay-retained FRC FDP.

In this part of the study, resin composite blocks were not reinforced with a fiber bundle and the height of the specimens was less than the pontic heights used in the first part of the study. On the other hand, the depth of the curves was kept standard by approximately 1.34 mm. Therefore, a direct correlation between the first part of the study was not made. Yet, the morphology created in Group (i) with ‘circular’ morphology showed similar contact with the loading sphere as in Group e...
where resin composite pontic had shallow anatomy and delivered the highest mean fracture strength values. In both parts of the study, fracture strength values showed similarities. On the other hand, Groups (ii) and (iii) with ‘elliptic’ morphologies may resemble to Groups a, b, c and d. However, since all pontic materials, such as the acrylic denture teeth, porcelain denture teeth, natural teeth and free-hand constructed composite resin, used in the study do not have identical occlusal morphologies, it is difficult to compare the fracture strength values among the pontic materials with different morphologies. This could be perceived as the limitation of this study. In spite of that, in clinical situations a similar situation also exists.

In future studies, affect of pontic materials and pontic morphology in combination with FRC FDPs should be tested under dynamic loading\textsuperscript{30}. Also, in-vitro studies should mention the loading area, occlusal morphology, and loading conditions in similar studies in order to make direct comparisons with this study.

CONCLUSION

Within the limitations of this study, the following conclusions were drawn:
1. Natural teeth, acrylic, porcelain denture teeth or resin composite can all be used as pontic materials for inlay-retained FRC FDPs without affecting the static fracture resistance.
2. Forces applied on bucco-lingual occlusal contact points significantly decreased the fracture resistance of composite blocks.
3. The occlusal morphology of the pontic significantly affects the fracture resistance of FRC FDPs.

REFERENCES


