MEDICAL SCIENCE MONITOR

LAB/IN VITRO RESEARCH

e-ISSN 1643-3750
© Med Sci Monit, 2018; 24: 4440-4448
DOI: 10.12659/MSM.909271

Received: 2018.01.31
Accepted: 2018.03.06
Published: 2018.06.28

Comparison of Load-Bearing Capacities of 3-Unit Fiber-Reinforced Composite Adhesive Bridges with Different Framework Designs

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

ABF 1 **Ibrahim H. Tacir**
ABC 2 **Roda S. Dirihan**
AB 1 **Zelal Seyfioglu Polat**
BDE 3 **Gizem Ön Salman**
ACEF 2 **Pekka Vallittu**
ACDE 2 **Lippo Lassila**
E 1 **Emrah Ayna**

1 Department of Prosthetic Dentistry, Faculty of Dentistry, Dicle University, Diyarbakir, Turke
2 Department of Biomaterials Science, Institute of Dentistry, Faculty of Medicine, University of Turku, Turku, Finland
3 DClinDent Bursa Oral and Dental Health Hospital, Bursa, Turkey

Corresponding Author: Emrah Ayna, e-mail: emrah.ayna@dicle.edu.tr

Source of support: Departmental sources

Background: The aim of this study was to investigate and compare the load-bearing capacities of three-unit direct resin-bonded fiber-reinforced composite fixed dental prosthesis with different framework designs.

Material/Methods: Sixty mandibular premolar and molar teeth without caries were collected and direct glass fiber-resin fixed FDPs were divided into 6 groups (n=10). Each group was restored via direct technique with different designs. In Group 1, the inlay-retained bridges formed 2 unidirectional FRC frameworks and pontic-reinforced transversal FRC. In Group 2, the inlay-retained bridges were supported by unidirectional lingual and occlusal FRC frameworks. Group 3, had buccal and lingual unidirectional FRC frameworks without the inlay cavities. Group 4 had reinforced inlay cavities and buccal-lingual FRC with unidirectional FRC frameworks. Group 5, had a circular form of fiber reinforcement around cusps in addition to buccal-lingual FRC frameworks. Group 6 had a circular form of fiber reinforcement around cusps with 2 bidirectional FRC frameworks into inlay cavities. All groups were loaded until final fracture using a universal testing machine at a crosshead speed of 1 mm/min.

Results: Mean values of the groups were determined with ANOVA and Tukey HSD. When all data were evaluated, Group 6 had the highest load-bearing capacities and revealed significant differences from Group 3 and Group 4. Group 6 had the highest strain ($p>0.05$). When the fracture patterns were investigated, Group 6 had the durability to sustain fracture propagation within the restoration.

Conclusions: The efficiency of fiber reinforcement of the restorations alters not only the amount of fiber, but also the design of the restoration with fibers.

MeSH Keywords: **Adhesives • Composite Resins • Light-Curing of Dental Adhesives**

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/909271

2929 4 6 32

This work is licensed under Creative Common Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

Background

Fiber-reinforced composite fixed partial dentures are preferred restorations because they are minimally invasive, metal-free, and good esthetic restorations for replacing missing single or multiple anterior or posterior teeth [1–3]. RC-FPDs should be applied with direct technique, with no need for a second clinic visit [2].

Multiple studies have assessed different types of FRC frameworks used with or without inlay preparation of the abutment, and the results suggest that high-volume fraction frameworks provide better clinical success than low-volume fraction frameworks due to lack of support for the veneering composite of the pontics [4,5]. The FRC framework provides stronger resistance against biting force. Failure modes seen in weak restorations, like interdental connectors, include delamination of unsupported veneer material by FRC [6–8]. Göhring et al. [9] reported on a two-year clinical and scanning electron microscopy (SEM) evaluation of glass fiber-reinforced inlay fixed partial dentures. While FRC-FPDs were clinically successful in most criteria, after 2 years, they also reported delaminations of veneering composite from the fiber framework and concluded that more research on the framework design was necessary. Monaco et al. [10] reported the results of a study of glass fiber reinforced inlay-retained FPDs over a period of 1–4 years. A conventional (unidirectional pontic fibers only) and a modified (unidirectional, woven frame fibers for buccolingual support) framework design were evaluated. The modified framework design showed a lower fracture rate of the veneering composite. To overcome these failures, the different framework design should be modified to support the veneering composite, and the amount of fibers should be increased to improve the rigidity of the FPD [2,10–12]. A number of studies have examined the fracture resistance of the pontic used for the fabrication of FRC-FPDs to evaluate either fiber position or volume.

The aim of the present study was to investigate and compare the load-bearing capacity of three-unit direct resin-bonded fiber-reinforced composite fixed partial dentures with different framework designs.

Material and Methods

Sixty mandibular second premolars and first molars without caries were collected, cleaned, and stored in 0.1% chloramine T (n-chloro-para-toluene sulfonamide sodium salt) for approximately 2 months prior to the experiment. The model was arranged for the standardization of the fixed dental prosthesis (FDP), which simulated the situation of the lower first molar and premolar on the arc. A mold was made using a negative composite FDP with vinyl polysiloxane, which was prepared on this model to make restorations (Table 1).

The blocks were prepared by using autopolymerized acrylic and were used as stands for placing the teeth. Two slots were opened on the block surface. The abutment teeth were immobilized to prepared slots via light-curing resin so as to simulate lack of the lower molar tooth with a mesiodistal distance of 11 mm. The specimens were randomly divided into 6 groups of 10 teeth each (n=10). Each group was restored via direct technique with different designs.

A distoocclusal cavity was prepared for the second premolar tooth (step: 3.0×2.0 mm; box: 1.5×3.5 mm; depth: 2.0 mm)

Table 1. Materials and contents.

Material	LOT No.	Characteristics	Composition
EverStick, Sticktech Ltd. Turku Finland	2090107-D7-002	Fiber-reinforced unidirectional e-glass	E-glass, PMMA Bis-GMA
Stickflow, Sticktech Ltd. Turku Finland	580111519	Light-cured flow composite restorative material	Bis-GMA, TEGDMA, PMMA
Experimental composite 1		Light-cured composite restorative material	Bis-GMA,TEGDMA, DMAEMA
Adper™ Scotchbond™, 3M ESPE, Germany	352388	Multipurpose adhesive resin luting material	BisGMA, HEMA
Memosil2, Heraeus Germany	295321	Translussent polyvinyl siloxane for direct application	Vinyl siloxane
Palapress Heraeus Germany	012501	Self polymerizied acyrylic resin for lab application	Powder: methylmetacrylate-copolymer Liquid: dimethylmetacyrilat (cadmium-free)

This work is licensed under Creative Common Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)

Figure 1. View of the inlay-retained 3-unit FRC-FPD.

and a mesioocclusal preparation was used for the second molar (step: 4.0×3.0 mm; box: 1.5×5.0 mm; depth: 2.0 mm). Inlay cavities were made with conventional diamond burs (set4278, Komet, Lemgo, Germany) in Group 1, Group 2, Group 4, and Group 6. All-etch technique was applied to half of the buccal-lingual binding surfaces with 37% phosphoric acid for 15 s, according to the design of the inlay cavities. The cavities were then rinsed thoroughly with water for 15 s and gently air-dried. The adhesive system (Adper™ Scotchbond Multipurpose, 3M ESPE, USA) containing separate primer and adhesive resin was used according to the manufacturer's instructions. The adhesive resin was polymerized with a light-curing unit (Demi, Kerr™, USA) for 20 s. A one-way glass FRC piece (EverStick C & B, Stick Tech, Turku, Finland), which could be polymerized with a light, was placed in the molar from the premolar in the mesiodistal direction and slightly inclined towards the alveolar crest.

In Group 1, the inlay-retained bridges formed 2 unidirectional FRC frameworks from the cavity-to-cavity and step-to step, and the pontic supported a piece of FRC in transversal direction (Figure 1). In Group 2, inlay-retained bridges were supported in lingual and occlusal direction FRC frameworks and in Group 3 pontics were formed in buccal and lingual direction FRC frameworks without the inlay cavities. In Group 4, FRC was placed on both inlay cavities and buccal-lingual surfaces of teeth. In Group 5 we prepared a circular form of fiber reinforcement around cusps of the pontic in addition to buccal and lingual FRC frameworks. In Group 6 we formed a circular form of fiber reinforcement around cusps of the pontic with 2 unidirectional FRC frameworks between inlay cavities and steps. A thin layer of flowable composite resin (Stickflow, Stick Tech, Turku, Finland) was then applied to bottom of the cavities and half of the buccal-lingual surfaces that contacted with FRCs (Figure 2). On each pontic we applied a thin layer flowable composite to the FRC framework, achieved by use of a polyvinyl template with particular composite and polymerized for 40 s using a hand-held light-curing unit.

All FDPs were stored at 37°C for 4 days before being tested in distilled water. A steel ball with a contact cusp surface (4 mm) was seated to the central occlusal fossa (Figure 3). All groups were loaded until final fracture using a universal test machine (model LRX, Lloyd Instruments Ltd., Fareham, UK) at a crosshead speed of 1 mm/min. Data were saved using PC software. Then, the strain of fracture of the FDP on the pontic due to the applied force was recorded. After each fracture test, the failure type and location of the fracture were examined visually with a stereomicroscope (Figure 4). Statistical analyses were performed using SPSS software (SPSS 16.0 for Mac, Chicago, IL). Mean values of load-bearing capacity and the magnitude of strain were compared between the group**s** using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test ($p<0.001$).

Results

The mean load-bearing capacities were 1031.01 N for Group 1, 1085.87 N for Group 2, 950.43 N for Group 3, 933.84 N for Group 4, 1090.13 N for Group 5, and 1301.52 N for Group 6 (Table 2; Figure 5).

The magnitude of fracture strain was 1.99 mm for Group 1, 1.84 mm for Group 2, 1.56 mm for Group 3, 1.94 mm for Group 4, 1.57 mm for Group 5, and 2.38 mm for Group 6 (Table 3; Figure 6).

In most of the FDPs, a veneer lamination type of fracture was observed, resulting in the separation of the composite resin veneer superstructure pieces without leaving the fiber. In buccal- and/or lingual enamel-supported restorations, we found that these holders were separated on some teeth. Connector fracture was most common in Group 5 restorations, which were supported by circumferential fiber of the pontic. Although Group 6 restorations had the highest load-bearing capacity,

This work is licensed under Creative Common Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)

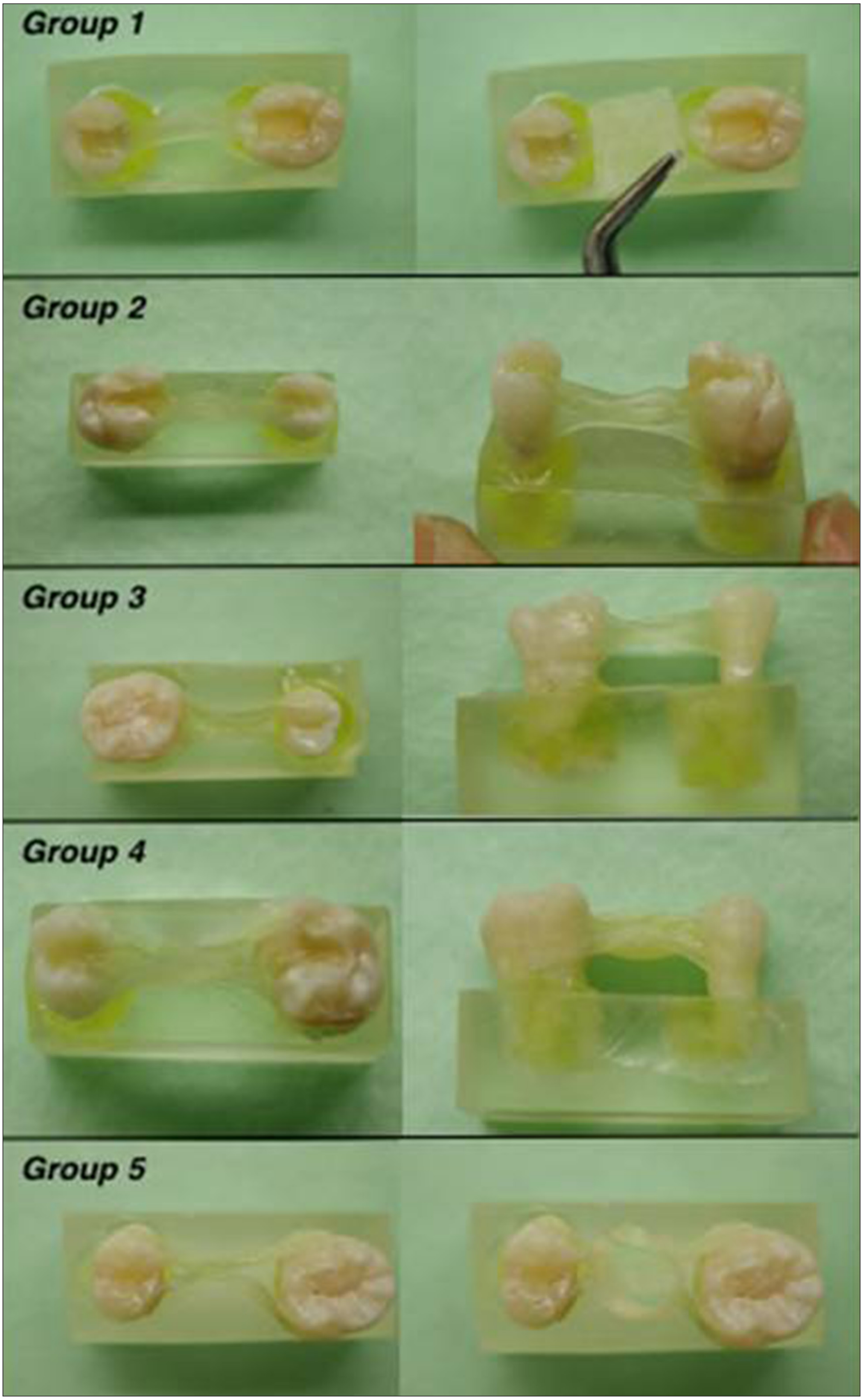

Figure 2. Preparation of groups.

This work is licensed under Creative Common Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)

Figure 3. Placement of the steel ball to occlusal fossa.

8 of the FDPs displayed non-visible internal fractures and 2 samples displayed repairable veneer delamination. All FDPs in this group were considered successful enough to maintain their function (Table 4).

Discussion

When all data were evaluated, Group 6 had the highest load-bearing capacity and revealed significant differences from Group 3 and Group 4. Group 4 had the lowest load-bearing capacity, but the difference was not statistically significant. Group 6 had the highest bending value ($p>0.05$) and Group 3 has the lowest bending value ($p\leq0.05$).

FRCs have suitable flexural modulus and flexural strength for functioning successfully in the mouth as a restorative material [13]. Previous studies reported that the static load-bearing capacity of FRC-FPDs range from 524 N [14] to 2500 N [4], but these results could change depending on material properties, fiber orientation, preparation type of abutment, and framework design [15]. In the present study, Group 4 had the lowest fracture strength (933.84±200.21 N), but was still acceptably strong in terms of mean masticatory forces for posterior teeth because maximum stress values for posterior teeth are acceptable at 500–900 N [16].

In a review by Van Heumen et al. [17] of articles on FRC-FPDs published between 1950 and 2007 and found in a search of PubMed, studies mostly focussed on pontic span length, design of the restoration, abutment preparation, and fiber position and quantity. Van Heumen reported that failures were not only due to major causes such as delamination or debonding between fiber and composite, but were also due to minor causes such as cracks, discoloration, and posterior location, and length of span had a failure risks for FRC-FPDs. A systematic review by Ahmed et al. [18] showed that FRC-FPDs offer a medium-term management alternative for replacing missing single anterior or posterior teeth. Valittu et al. [19] reported a 75% success rate of 29 fiber-reinforced composite restorations as a result of 5 years of clinical follow-up studies. Two failure causes had irreversible damage and 3 resulted in de-cementation. However, 97% of recemented restorations maintained their function. Such restorations appear to offer a reliable, minimally invasive, esthetic, cost-efficient way to restore missing single teeth with predictable clinical performance and good patient outcomes.

FRC-FPDs require minimum or no preparation of abutment teeth in order to replace missing teeth. Depending on the clinical situation, however, adequate space is required for fiber infrastructure and resin veneering composites, especially in posterior applications. Composite erosion when the area is inadequate may result in early failure of the restoration, as well as exposure to plaque buildup on the fiber. van Heumen et al. [20] demonstrated a higher 5-year survival probability for inlay-retained posterior FPDs when compared to surface or hybrid retained designs (82% *vs.* 78% and 66%, respectively) but the difference was not statistically significant. In the present study, retention of the restoration to abutment was provided via conventional inlay cavity preparation in Group 1, Group 2, Group 4, and Group 6, and bonding to buccal-lingual enamel surfaces in Group 3 and Group 5 with FRC retainers. Hybrid retained designs were used in Group 2 and Group 4. Inlay-retained restorations (Group 1 and Group 6) had the highest fracture strength and these groups had lower standard deviations than the other groups, meaning these restoration and cavity types were more reliable. Additionally, concentration and placement of fiber directly affected the mechanic properties of the restoration. Homogeneity of fiber and selected design should support the restoration in all directions [21]. Song et al. [22] reported that the span of FPDs affected the results and the inlay cavity preparation technique provided acceptable results on adhesive FPDs when it was compared with formed tube cavity.

Freilich et al. [12] compared the success of heat- and light-polymerized fiber-reinforced composite restorations in 39 patients. They used indirect technique in 22 patients and direct technique in 17 patients, and then followed their success for 37 months. Initially, FRCs with low-volume substructure exhibited lower clinical survival than high-volume ones. In patients who had severe parafunctional habits, the success rate of high-volume FRCs was 95%. After 24 months, only 2 restorations had

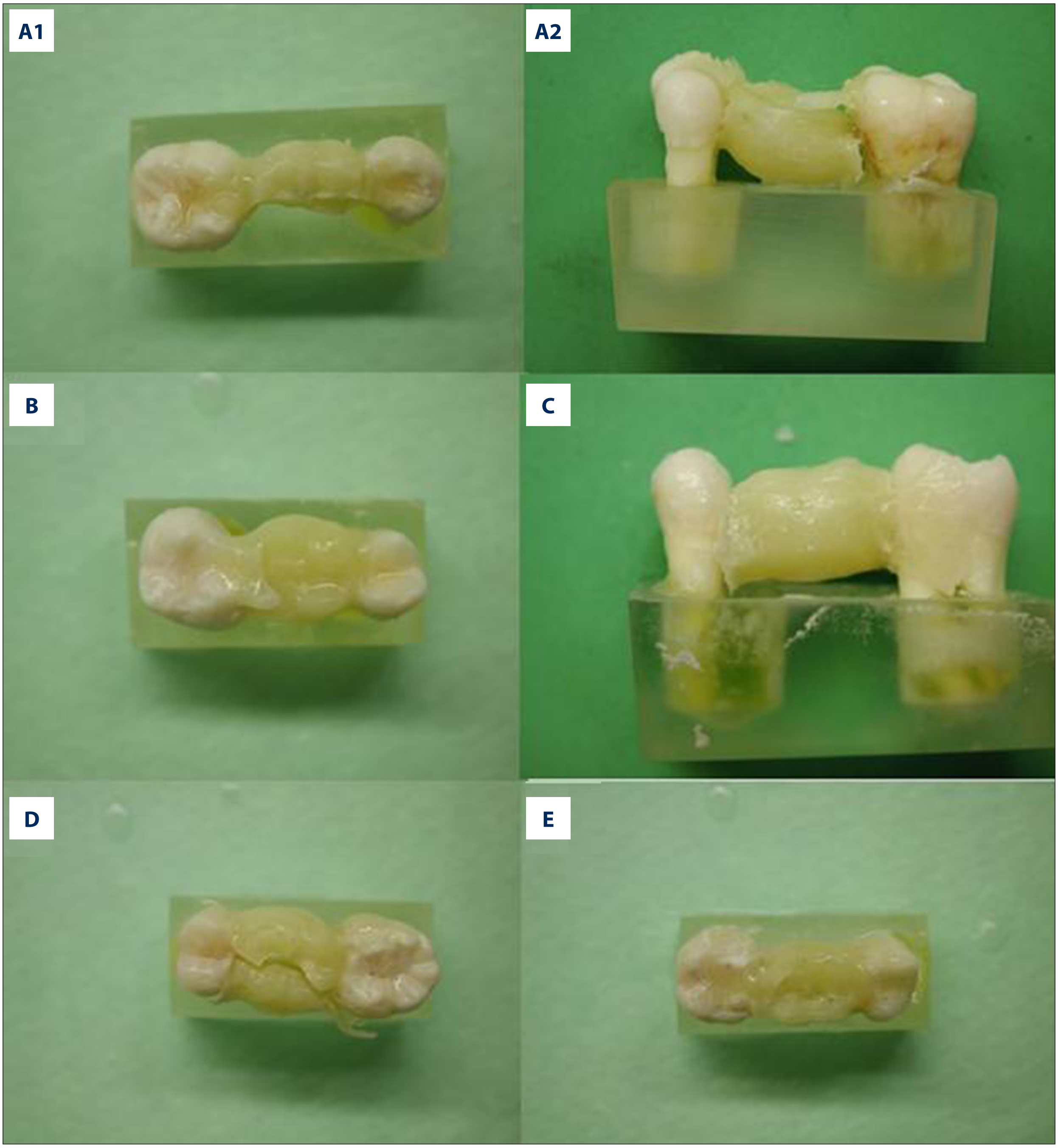

Figure 4. Fracture pattern of FRC-FPDs. (**A1, A2**) pontic fracture, (**B**) veneer delamination, (**C**) connector fracture, (**D**) decementation, (**E**) invisible fracture.

repairable surface defects and SEM examinations showed no fibers exposed on occlusal surfaces. They reported that bridge restorations made with unidirectional, pre-impregnated, high-volume FRCs maintain their function at least 4 years. The authors stated that for short-span prothesis; hybrid particulate composite and unidirectional FRC substructures showed the same successful results as metal substructures. In the same study, it was emphasized that not all FRCs are the same; clinicians should be aware that the type of FRC, whether it is pre-impregnated, the design, the tooth surface characteristics, and the particulate composite all affect the success rate. The authors also stated that the volume of fiber was more important than whether the restoration technique is direct or indirect. Actually, what is important here is the use of high-volume fibers. Strength of the restoration depends on adhesion between veneer and FRC construct, tooth, and retainer. Eckrote et al. [23]

This work is licensed under Creative Common Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)

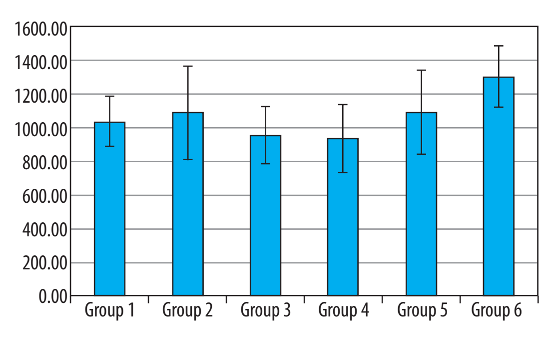

Figure 5. The means and standard deviations of the groups with regard to results of the fracture strength testing.

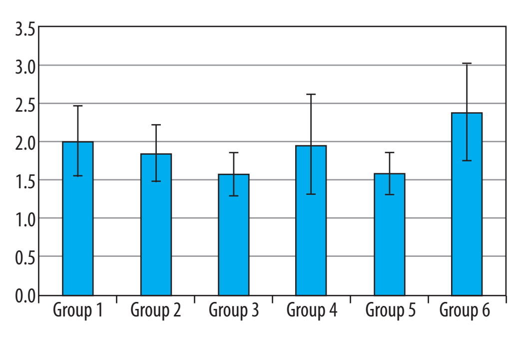

Figure 6. The means and standard deviations of amount of bending of the groups according to results of the fracture strength testing.

Table 2. The means and standard deviations of the groups with regard to results of the fracture strength testing.

Group	Mean (N)	SD	Min	Max
Group 1	1031.01	146.12	818.82	1238.21
Group 2	1085.87	277.87	704.20	1469.70
Group 3	950.43	170.28	719.21	1194.36
Group 4	933.84	200.21	720.85	1183.65
Group 5	1090.13	233.13	899.88	1544.11
Group 6	1301.52	181.19	1026.70	1575.46

Table 3. The means and standard deviations of amount of bending of the groups according to results of the fracture strength testing.

Group	Mean (N)	SD	Min	Max
Group 1	1.99	.46	1.46	3.01
Group 2	1.84	.37	1.45	2.51
Group 3	1.56	.28	1.09	2.01
Group 4	1.94	.65	1.27	3.15
Group 5	1.57	.27	1.15	1.96
Group 6	2.38	.63	1.78	3.72

Table 4. The fracture patterns of groups.

Group	Veneer delemination	Pontic fracture	Connector fracture	Decementation	Invisible fracture
Group 1	7	3	–	–	–
Group 2	3	3	–	4	–
Group 3	3	2	–	5	–
Group 4	6	1	–	3	–
Group 5	3	–	7	–	–
Group 6	2	–	–	–	8

This work is licensed under Creative Common Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)

examined effects fracture resistance of different restoration designs, showing that the pontic must be supported by different directional fiber pieces. Similarly, Waki et al. [24] evaluated the efficiency of different fiber localizations and the effect of maximum load-bearing capacity of FRC-FPDs. The design that curved towards the bottom of the pontic had a better reinforcement framework. Waki et al. emphasized that the stress center of the restoration was near the bottom side of the pontic. In the present study, FRC substructure was supported towards the bottom of the pontic in all of the 6 different designs. Composite veneer material was reinforced with inset fiber. The prepared pontic used in Group 1 was formed by 2 unidirectional FRCs between cavities and steps, and the restoration was supported transversally by a piece of FRC that reinforced the veneer composite. However, the reinforced circular FRC used in Group 5 and Group 6 had higher fracture strength than in the other groups. When circular FRC was compared, bidirectional reinforcement had better fracture strength. Group 1 and Group 6 were the most reliable designs when standard deviations of groups were compared. Consequently, Group 5 and 6 had higher fracture strength values than in the other groups because the FRC supported the pontic.

Shi and Fok [6] prepared an FEM test for developing strength and optimized fiber position of 3-unit FRC-FPDs, showing that the bottom of the pontic and connectors determined the highest stress area. Also, conventional inlay preparation was found to be the strongest cavity design. In other words, conventional inlay cavity and fiber placed near the bottom of the pontic were important in optimizing fiber localization. Özcan et al. [25] evaluated the effect of pontic materials on the fracture resistance of fiber-reinforced composite (FRC) inlay-retained fixed dental prostheses (FDP), reporting that the pontic material did not affect the fracture resistance of FRC FDPs. In the present study, composite resin material was used as a pontic because it is easy to use, has good mechanical properties, and can be used both chair-side and in the laboratory.

The study process, from preparation to test method, should be similar to other studies in terms of the physical properties of the materials and testing techniques used. Rosentritt et al. [26] stated that even if metal-made abutments provided an advantage for standardization, they had the disadvantages of not being affected by elastic modulus, fracture strength, liquid, and thermal conditions. A previous study showed that natural teeth have lower fracture strength compared to the fracture strength of liquid polymer.

Researchers often used a steel ball as a loading tip, with scales ranging from 2.5 mm to 14.5 mm. Another study report that at the beginning of the test, the distance between the loading tip and the sample should be 0.4–1 mm. Also, the anatomic characteristics of the tooth determine the crest form of the loading machine [27]. In the present study, the size of the steel ball was 4 mm; it was seated in the central occlusal fossa of the first lower molar for loading and contacted with cusps approximately 0.5 mm from the test tip.

Song et al. [22] found an inverse relationship between elastic modulus of the materials and bending of the restorations. Researchers suggest that the modulus of elasticity of the material is close to that of e dentin and enamel because there is a correlation between the fracture resistance and the modulus of elasticity. In the present study, Group 6, which had the highest fracture strength value, also had the highest amount of bending (2.38 mm), and the maximum bending was observed in the region where the highest force was applied. Group 6 was supported by inlay-retained cavity. Group 1 restorations, which were only supported by inlay-retainer, had the second highest amount of bending. Thus, these groups have the most reliable designs in all groups.

The path of the fracture is an important parameter for fracture type. Some studies have determined the fracture forces of FPDs by determining the initial failure originating from the force deviation curve [28,29]. Fracture line is an appropriate indicator of fracture pattern. A more precise method for determining the first fault point is based on determining the onset of AE signals [30]. The first cracking and fracture of the material can be evaluated by material acoustic emission (AE) signals [31,32]. AE, also known as "stress wave emission", is a term that describes the acoustic stress waves that occur when energy is rapidly released due to microstructure changes in a material during sudden movements [30]. Acoustic emission is the elastic energy that is spontaneously released by materials when they undergo deformation. In the present study, we observed that fractures in Group 5 and Group 6 differed from those in the other groups, particularly in Group 6, in which inlay cavity support showed no visible fracture and the fracture strength test was ended according to the acoustic emission the device perceives. However, none of the specimens had fiber coming out. In other words, all specimens have the necessary properties to maintain their functions in intraoral conditions. The most common fracture pattern in Group 5 was connector loss. Comparing the design of Group 6 with Group 5, it appears that the inlay-retained cavity is more resistant to fracture forces than the adhesive provided by the enamel surface.

Conclusions

- All 6 framework designs provided satisfactory high fracture resistance, assuming maximum chewing forces of >500 N in posterior areas.
- The load-carrying capacity was increased by placing an additional circular FRC on the occlusal surface of the pontic framework.

This work is licensed under Creative Common Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)

– Investigation of fracture types showed restorations with circular FRC had the highest fracture strength and the durability to sustain restorations.

– The efficiency of fiber reinforcement was acceptable as a successful restoration, increasing support to the composite resin with different direction and pontic reinforcement.

References:

1. Valittu P: Survival rates of resin-bonded, glass fiber-reinforced fixed partial dentures with a mean follow-up of 42 months: A pilot study. J Prosthet Dent, 2004; 91: 241–47
2. Göhring T, Ross M: Inlay-fixed partial dentures adhesively and reinforced by glass fibre: clinical and scanning electronic microscopy analysis after five years. Eur J Oral Sci, 2005; 113: 60–69
3. Lindquist E, Karlsson S: Success rate and failure for fixed partial dentures after 20 years of service: Part 1. Int J Prosthodotics, 1998; 11: 133–38
4. Xie Q, Lassila L, Vallittu P: Comparison of load-bearing capacity of direct resin-bonded fiber-reinforced composite FPDs with four framework designs. J Dent, 2007 ;35: 578–82
5. Behr M, Rosentritt M, Taubenhansl P et al: Fracture resistance of fiber-reinforced composite restorations with different framework design. Acta Odontol Scand, 2005; 63: 153–57
6. Shi L, Fok A: Structual optimization of the fibre-reinforced composite substructure in a three-unit dental bridge. Dent Mater, 2009; 25: 791–801
7. Tinschert J, Natt G, Maustsch W et al: Fracture resistance of lithium disilicate alumina and zirconia based three unit fixed partial dentures: A laboratory study. Int J Prosthodotics, 2001; 13: 420–24
8. Anusavice K: Informatics systems to assess and apply clinical research on dental restorative materials. Adv Dent Res, 2003; 17: 43–48
9. Göhring T, Schmidlin P, Lutz F: Two-year clinical and SEM evaluation of glass-fiber-reinforced inlay fixed partial dentures. Am J Dent, 2002; 15(1): 35–40
10. Monaco C, Ferrari M, Miceli G, Scotti R: Clinical evaluation of fiber reinforced composite inlay FPDs. Int J Prosthodotics, 2003; 16: 319–25
11. Behr M, Rosentritt M, Latzel D, Handel G: Fracture resistance of fiber reinforced *vs.* non fiber reinforced composite molar crowns. Clin Oral Investig, 2003; 7: 135–39
12. Freilich M, Meiers J, Duncan J et al: Clinical evaluation of fiber-reinforced fixed bridges. J Am Dent Assoc, 2002; 133: 1524–34
13. Alander P, Lassila L, Tezvergil A, Valittu P. Acoustic emission analysis of fiber-reinforced composite in flexural testing. Dent Mater, 2004; 20: 305–12
14. Behr M, Rosentritt M, Ledwinsky E, Handel G: Fracture resistance and marginal adaptation of conventionally cemented fiber-reinforced composite three-unit FPDs. Int J Prosthodont, 2002; 15(5): 467–72
15. Keulemans F, Lassila L, Garoushi S et al: The influence of framework design on the load-bearing capacity of laboratory-made inlay-retained fibre-reinforced composite fixed dental prostheses. J Biomech, 2009; 42: 844–49
16. Valittu P, Könönen M: Prosthodontic materials. Biomechanical aspects and materials properties. In: A textbook of fixed prosthodontics. 2000; 116–30
17. Van Heumen C, Kreulen C, Creugers N: Clinical studies of fiber-reinforced resin-bonded fixed partial dentures: A systematic review. Eur J Oral Sci, 2009; 117: 1–6
18. Ahmed K, Li K, Murray C: Longevity of fiber-reinforced composite fixed partial dentures (FRC FPD) – systematic review. J Dent, 2017; 61: 1–11
19. Valittu P, Sevelius C: Resin-bonded, glass fiber-resin-forced composite fixed partial dentures: A clinical study. J Prosthet Dent, 2000; 84: 413–18
20. Van Heumen C, Tanner J, Van Dijken J et al: Five-year survival of 3-unit fiber-reinforced composite fixed partial dentures in the posterior area. Dent Mater, 2010; 26: 954–60
21. Dyer S, Sorensen J, Lassila L, Valittu P: Damage mechanics and load failure of fiber-reinforced composite fixed partial dentures. Dent Mater, 2005; 21(12): 1104–10
22. Song H, Yi Y, Cho L, Park D: Effects of two preparation designs and pontic distance on bending and fracture strength of fiber-reinforced composite inlay fixed partial dentures. J Prosthet Dent, 2003; 90: 347–53
23. Eckrote K, Burstone C, Freilich M et al: Shear in flexure of fiber composites with different end supports. J Dent Res, 2003; 82: 262–66
24. Waki T, Nakamura T, Nakamura T et al: Fracture resistance of inlay-retained fixed partial dentures reinforced with fiber-reinforced composite. Dent Mater J, 2006; 25: 1–6
25. Özcan M, Breuklander M, Yener E: Fracture resistance of direct inlay-retained adhesive bridges: Effect of pontic material and occlusal morphology. Dent Mater J, 2012; 31: 514–22
26. Rosentritt M, Plein T, Kolbeck C, Handel G: *In vitro* fracture force and marginal adaptation of ceramic crowns fixed on natural and artificial teeth. Int J Prosthodotics, 2000; 13: 387–91
27. Seghi R, Sorensen J: Relative flexural strength of six new ceramic materials. Int J Prosthodont, 1995; 8: 239–45
28. Gutteridge D: Reinforcement of poly(methyl methacrylate) with ultra-high-modulus polyethylene fibre. J Dent, 1992; 20: 50–54
29. Nohrstrom T, Valittu P, Yli-Urpo A: The effect of placement and quantity of glass fibers on the fracture resistance of interim fixed partial dentures. Int J Prosthodont, 2000; 13: 72–78
30. Hamstad M: Composite characterization techniques: Acoustic emission. Acoust Emiss US Army Mantech J, 1985; 10: 24–32
31. Hamstad M: Testing fiber composites with acoustic emission monitoring. J Acoust Emiss, 1982; 1: 151–64
32. Hamstad M: A review: Acoustic emission, a tool for composite-materials studies. Exp Mech, 1986; 26: 7–13

This work is licensed under Creative Common Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)