Effect of Different Framework Materials of Resin-Bonded Bridges on Load to Fracture Values and Stress Distribution

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Abstract

Purpose: The aim of this study was to compare *in vitro* fracture strengths (FSs) of metal- and fiber-reinforced frameworks of resin-bonded bridges and to evaluate stress distribution with finite element analysis (FEA). **Materials and Methods:** Totally 80 extracted maxillary central and maxillary canine teeth were used for *in vitro* part of this study as two groups; metal-reinforced framework (n = 20) [(metal-supported resin-bonded bridge (MR-RB)] and fiber-reinforced frameworks (n = 20) [fiber-reinforced resin-bonded bridge (FR-RB) were prepared for three unit resin-bonded bridges. All bridges were loaded from lateral pontic at 1 mm/min crosshead speed and fracture values were recorded. Mann–Whitney *U*-test was used for statistical analysis, and fracture patterns were evaluated visually. FEA was carried out in the second part of the study, and stress distribution of MR-RB and FR-RB structures was analyzed using one of the models from *in vitro* specimens as main model. **Results:** The mean FSs of MR-RB and FR-RB were 637.47 ± 151.91 N and 224.86 ± 80.97 N, respectively. Fiber-reinforced specimens were found to distribute stress more homogeneous and connectors in each framework were the regions where stress concentrated mostly. **Conclusion:** *In vitro* FSs of MR-RB and the stress concentration of the point that the forces were applied were higher as compared to other parts of the restoration. Furthermore, in contrast to FR-RB specimens, retainer tooth fractures were observed in MR-RB specimens.

Keywords: *Finite element analysis, fracture strength, resin-bonded bridges*

Introduction

As preparation in enamel and dentine could lead to irreversible damage to tooth structure, preserving tooth structure has importance while reconstructing missing tooth.[1,2] Metal or full ceramic restorations, removable dentures, implants, and resin-bonded bridges are among the treatment options to compensate single-tooth deficiencies.[2,3] Resin-bonded fixed prosthesis is a conservative treatment option.[4] Especially, during the healing period of a single-tooth implant or in a tooth loss caused by a trauma that implant treatment is contraindicated related to the growth pattern, resin-bonded bridges maintain function and esthetics.[5] It is important to develop esthetics besides function in the single-tooth deficiencies seen in anterior and premolar regions.[6] While metal–ceramic combination has esthetic disadvantages of metal substructure and the risk of allergic reactions,[7] glass-fiber-reinforced composites are used in many dental applications with increased interest in metal-free aesthetic dentistry,[2] and fiber-reinforced composite resin bridges can be applied for both anterior and posterior teeth.[8] Researches[6,9-11] on less invasive and metal-free treatments focused on fiber-reinforced fixed partial prostheses. Fiber-reinforced composites can be made of carbon–graphite fibers, aramid fibers, polyethylene fibers, and glass fibers. The most important reason for choosing composites reinforced with

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polyethylene and glass fibers is that carbon–graphite and aramid fibers are not efficient in terms of esthetics.[8] The selection and design of the material for the adhesive bridge is an important issue.[2]

In this study, it was aimed to evaluate the *in vitro* fracture resistance of metal-supported (Maryland) and fiber-reinforced resin bridges and to perform the stress analysis by the finite element stress analysis method.

Materials and Methods

In the first part of this *in vitro* study, 40 sound maxillary central and 40 canine teeth were used as retainers to mimic the lateral tooth defect with approval of the 27/01 protocol number of Kırıkkale University Medical Faculty Ethics Committee. The silicone impression of the maxillary phantom model (frasaco, Tettnang, Germany) was obtained, and central and canine teeth which are dimensionally similar to these central and canine negatives and have no cracks and decays were chosen to be retainers for missing lateral. Acrylic blocks were formed after the central and canine teeth were placed within the obtained silicone impression. Fiber-reinforced resin-bonded bridges (FR-RBs) (n = 20) and metal-supported resin-bonded bridges (MR-RBs) (n = 20) were produced. Co-Cr metal frameworks (Microlit isi; Schutz Dental, Germany) for MR-RB group were produced separately for each model by casting method. The mean thickness for wings was 0.5 mm and 3–4 mm for buccolingual size of pontic. FR-RB group which was reinforced by impregnated glass fibers (Interlig, Angelus, Brazil) was prepared by a single operator; flowable composite (Clearfil Majesty Flow; Kuraray, Tokyo, Japan) was used to support 0.2-mm-thick fiber strip and make a core in pontic. All restorations were cemented with an adhesive resin cement (Panavia F2.0; Kuraray). Subsequently, pontic of restorations were completed with hybrid composites (Clearfil AP-X; Kuraray) using modified ridge lap design. The specimens were stored in water for 24 h, and then fracture strength (FS) values were recorded by applying load at 45° to the incisal edge of the pontic at a crosshead speed of 1 mm/min in a universal testing machine (Lloyd LRX, Ametek, UK) as well as fracture patterns were examined.

FS values obtained *in vitro* were evaluated statistically using SPSS 20.0 packet program. Hypothesis controls were performed at α = 0.05 significance level. Mann–Whitney *U*-test was used to compare FS.

In the second part of the study, both MR-RB and FR-RB adhesive restorations were modeled for the missing right lateral tooth in the maxillary for finite element analysis (FEA). Computer with 14 GB of RAM and Windows 7 Ultimate Version Service Pack 1 Operating System, Intel Xeon® R CPU 3,30 GHz processor, 500 GB hard disk; Activity 880 (smart optics Sensortechnik GmbH, Bochum, Germany) optical scanner and three-dimensional (3D) scanning device; Rhinoceros 4.0 (Seattle, WA, USA) 3D modeling software; VRMesh Studio (Virtual Grid Inc., Bellevue City, WA, USA) and Algor Fempro (Algor Inc., Pittsburgh, PA, USA) analysis program were used for 3D network structure and homogenization, 3D solid model creation, and FEA. Models were transferred to Algor Fempro (Algor Inc.) software in stl format for making analytical readings and analysis after being geometrically created with VR Mesh software. The material (elasticity modulus and Poisson's ratio) values describing the physical properties were given to each of the model structures [Table 1].[2,12,13]

Dental models were obtained by scanning one of the *in vitro* models which have right central and canine as retainers with a 3D smart optics scanner. Frameworks were designed on this model [Figure 1]. Retainer parts were accepted in enamel material. The other parts were Co-Cr, hybrid composite, glass fiber, and resin cement materials. The cement space for the restorations was determined to be 100 µm and cementation was completed. The models were transferred to the Fempro software by preserving the 3D coordinates. Solid model was constructed by bricks and tetrahedra elements. As a result of modeling, 131,368 nodes and 498,377 elements were identified. The models were fixed at the bottom and sides of the bone to have zero motion in the degree of freedom, which formed the boundary conditions. All models were accepted as linear, homogeneous, and isotropic materials. In the fiber model analysis, the glass fiber was considered orthotrophic and its values were given in three axes separately. The determined force was 154 N in the FEA. The load was applied at 135° to the incisal edge from the palatinal surface of the pontic and stress distributions were determined.

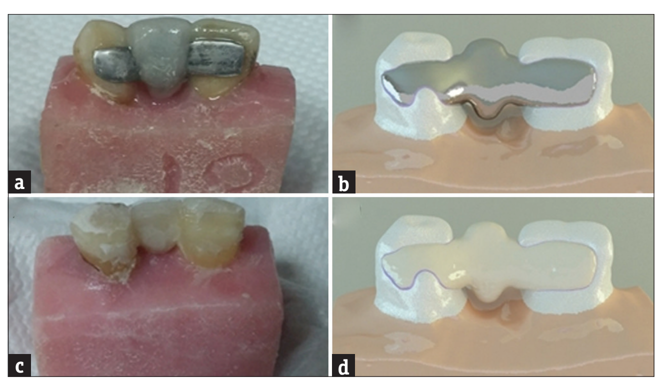

Figure 1: (a and b) *İn vitro* and 3D model of metal-reinforced framework. (c and d) *İn vitro* and 3D model of fiber-reinforced framework

Results

Fracture strength tests

The mean value of FS was 637.47 ± 151.91 N in the MR-RB group and 224.86 ± 80.97 N in the FR-RB group. Statistical analysis of our study revealed that there was a significant difference between MR-RB and FR-RB in terms of FS, and this significant difference was statistically found to be in favor of the metal substructure group ($U = 14$, $P < 0.05$).

The lowest FS value in the MR-RB group was 195.00 N, and the highest value was 843.58 N. In the FR-RB group, the lowest FS value was 117.36 N, while the highest value was 499.62 N.

When the fracture patterns were examined, it was found that there were retainer and veneer damages in the MR-RB group, whereas no framework fractures were detected. In the FR-RB group, veneer fractures and cracks were mostly observed, but no retainer fractures were detected. Decementation was obtained in the four specimens in this group without any cracks or fractures in the framework or veneer [Table 2].

Finite element analysis

The stresses were concentrated in the connector regions both in the metal-supported adhesive bridge model and in the fiber-supported adesive bridge model. When all the substructures were examined, it was concluded that stress distribution in the fiber-supported substructure [Figure 2] was more homogeneous than the metal-supported substructure [Figure 3 and Table 3].

The maximum stress values at the cement interface of the abutment teeth were obtained for metal framework

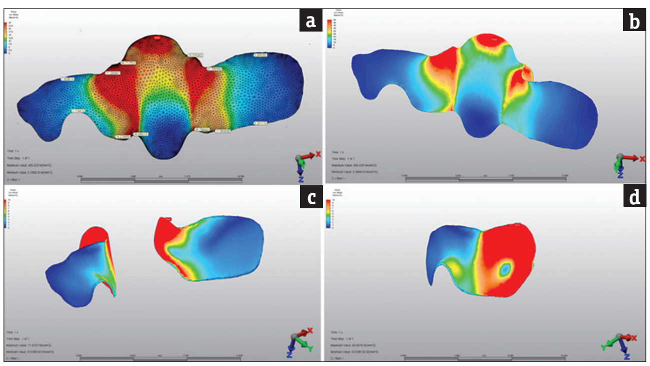

Figure 2: (a) Maximum stress distributions for glass fiber framework. (b) Maximum stress value in the pontic of the glass fiber framework; (c) maximum stress values in the mesial and (d) distal connection sites of the glass fiber framework

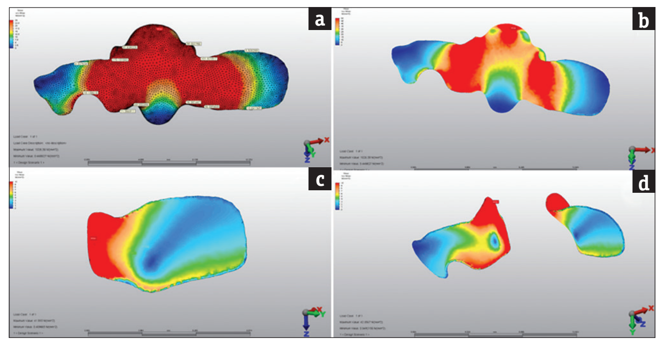

Figure 3: (a) Maximum stress distributions for metal framework. (b) Maximum stress value in the pontic of the metal framework. (c) The maximum stress values in the mesial and (d) distal connection sites of the metal framework

Table 1: Elastic modulus and Poisson's ratio of materials used in the study

Materials	Elastic modulus (GPa)	Poisson's ratio
Fiber framework[2]	Longitudinal X 3.90×10^4	0.35
	Transverse Y 1.20×10^4	0.11
	Transverse Z 1.20×10^4	0.11
Hybrid composite[2]	2.20×10^4	0.27
Enamel[8]	84.1	0.33
Resin cement[8]	9.5	0.24
Co-Cr[9]	218	0.33

Table 2: Fracture patterns of the *in vitro* restorations

Restoration	Framework fracture	Retainer fracture	Veneer delamination	Crack/fracture of veneer	Catastrophic fracture of veneer
FR-RB	2	0	0	14	0
MR-RB	0	8	5	3	4

FR-RB= Fiber-reinforced framework; MR-RB= Metal-reinforced framework

Table 3: Maximum principle stress values of finite element analysis

Restoration	Incisal of the pontic	Mesial connector	Distal connector
FR-RB	656.6 N/mm^2	71.9 N/mm^2	63.8 N/mm^2
MR-RB	1026.3 N/mm^2	41.5 N/mm^2	42.3 N/mm^2

FR-RB= Fiber-reinforced framework; MR-RB= Metal-reinforced framework sample as 58.0 N/mm^2 in the cervical third of the canine and for fiber-reinforced sample as 84.5 N/mm^2 in the incisal third of the central.

Discussion

Prosthetic treatment of cases with missing teeth in the anterior region, especially lateral tooth deficiencies, is widely restored with resin-bonded bridges because it is a safe and easy treatment alternative to conventional applications without giving any damage to sound retainer teeth.[14,15] Some points to note are important for the success of the treatment. The inclination between the retainers should not exceed 15° and they should be healthy.[16] Hence, in this study, extracted human teeth without any restoration or cracks were used for *in vitro* models which were prepared using silicone impression as a positional and dimensional reference. Adaptation of the extracted teeth to the central and canine cavities in the silicone impression which was obtained from the phantom model was controlled.

Resin-bonded bridges can be produced using metal, full ceramic, or fiber materials.[17] Fiber-reinforced restorations are good alternatives to the esthetic and allergic disadvantages of metal substructures.[15] Direct application improves the completion of restoration in less time by shortening the treatment session.[18] FS tests provide benefits in terms of comparing materials even though they do not provide information on the long-term prognosis of restorations.[19] Therefore, in the *in vitro* part of our study, the effect of frameworks on the FSs of MR-RB and RF-RB restorations was evaluated by FS test without thermal cycling by considering short-term usage periods of restorations, like in the previous study.[19] In the MR-RB group, all FSs obtained except the minimum value was found above the biting force range for the anterior region which is between 98 and 270 N.[20,21] In the mouth and in the FR-RB group except four specimens which were above 270 N, the fracture loads were in the range of 117, 36, and 257.72 N which were among the above-mentioned reference values.

Stress distributions that cannot be determined by mechanical tests on the materials used could be evaluated by virtual biomechanical methods such as finite element stress analysis.[22] Taking into account the above-mentioned bite force interval and as in the previous studies, a load of 154 N was applied to the incisal edge of the pontic at an angle of 135°, and stress distributions on the frameworks and retainers were determined. Incisal of the pontic and similar to previous studies,[17,23] the connector regions were identified as stress-intensified regions. However, contrary to the findings of Shinya *et al*.,[23] in this study, maximum stress values in the fiber framework were found higher than metal framework in the FEA. RF-RB was fractured with lower loads, whereas MR-RB was fractured at higher loads significantly in *in vitro* conditions. In FEA, it is suggested that higher stresses are generally obtained in the fiber framework, because the fiber substructure distributes the forces more homogeneously and absorbs more stress, so that it tends to break down with lower force than the metal.

Yokoyama *et al*.[17] reported that the preparation of the fiber-reinforced substructure to the labially curved provides the optimal distribution of stresses. In our study, the design of FEA and *in vitro* samples were prepared in a labially curved shape, slightly to the labial midpoint of the buccolingual distance of the pontic, although not as close to the labial as the previous study.[17]

Under *in vitro* conditions, it is reported that the cavity design does not increase the FS of FR-RBs significantly and no cavity preparation is stated to increase FS.[20] Hence, in our study, tests were carried out without preparation on the abutment teeth.

In a previous study, fiber-reinforced restorations were found to have higher flexural strengths and lower FSs.[10] In this study, metal and glass fiber frameworks used in resin-bonded bridges were thought that they would not make a significant difference in terms of FS and stress distributions, but a more homogeneous stress distribution was observed in glass fibers and FSs of metal substructure restorations were found to be significantly higher. The results of the study of Saridag *et al*. support our findings in the aspects of both *in vitro* and FEA evaluations.

Central and canine teeth used in *in vitro* conditions are not identical exactly, thus small differences may occur in restorations constituting the limitations of our study. Thermal changes and natural mobility of the teeth in oral conditions were not included, hence this affects obtaining clinically similar results. Besides, the effect of bond strengths of frameworks on FS and stress distribution must be considered in further studies.

Conclusion

With the limitations of the study it was observed that in vitro FSs of MR-RB and the stress concentration of the point that the forces were applied were higher as compared to other parts of the restoration. Furthermore, in contrast to FR-RB specimens, retainer tooth fractures were observed in MR-RB specimens.

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Conflicts of interest

There are no conflicts of interest.

References

1. Shillingburg HT, Hobo S, Whitsett LD, Jacobi R, Brackett SE. Fundamentals of Fixed Prosthodontics. 3rd ed. Chicago:Quintessence;1997. p. 537.
2. Yokoyama D, Shinya A, Gomi H, Vallittu PK, Shinya A. Effects of mechanical properties of adhesive resin cements on stress distribution in fiber-reinforced composite adhesive fixed partial dentures. Dent Mater J 2012;31:189-96.
3. Javaheri DS. Replacement of an anterior tooth with a fiber-reinforced resin bridge. Compend Contin Educ Dent 2001;22:68-70, 72, 74.
4. Magne P, Perakis N, Belser UC, Krejci I. Stress distribution of inlay-anchored adhesive fixed partial dentures: A finite element analysis of the influence of restorative materials and abutment preparation design. J Prosthet Dent 2002;87:516-27.
5. Zitzmann NU, Özcan M, Scherrer SS, Bühler JM, Weiger R, Krastl G, *et al.* Resin-bonded restorations: A strategy for managing anterior tooth loss in adolescence. J Prosthet Dent 2015;113:270-6.
6. Keulemans F, De Jager N, Kleverlaan CJ, Feilzer AJ. Influence of retainer design on two-unit cantilever resin-bonded glass fiber reinforced composite fixed dental prostheses: An *in vitro* and finite element analysis study. J Adhes Dent 2008;10:355-64.
7. Wataha JC. Alloys for prosthodontic restorations. J Prosthet Dent 2002;87:351-63.
8. Freilich MA. Fiber-Reinforced Composites in Clinical Dentistry. Chicago: Quintessence Publishing; 2000.
9. Fonseca RB, de Almeida LN, Mendes GA, Kasuya AV, Favarão IN, de Paula MS, *et al.* Effect of short glass fiber/filler particle proportion on flexural and diametral tensile strength of a novel fiber-reinforced composite. J Prosthodont Res 2016;60:47-53.
10. Saridag S, Ozyesil AG, Pekkan G. Fracture strength and bending of all-ceramic and fiber-reinforced composites in inlay-retained fixed partial dentures.J Dent Sci 2012;7:159-64.
11. Kumbuloglu O, Özcan M. Clinical survival of indirect, anterior 3-unit surface-retained fibre-reinforced composite fixed dental prosthesis: Up to 7.5-years follow-up. J Dent 2015;43:656-63.
12. Perillo L, Sorrentino R, Apicella D, Quaranta A, Gherlone E, Zarone F, *et al.* Nonlinear visco-elastic finite element analysis of porcelain veneers: A submodelling approach to strain and stress distributions in adhesive and resin cement. J Adhes Dent 2010;12:403-13.
13. Sevimay M, Turhan F, Kiliçarslan MA, Eskitascioglu G. Three-dimensional finite element analysis of the effect of different bone quality on stress distribution in an implant-supported crown. J Prosthet Dent 2005;93:227-34.
14. Garnett MJ, Wassell RW, Jepson NJ, Nohl FS. Survival of resin-bonded bridgework provided for post-orthodontic hypodontia patients with missing maxillary lateral incisors. Br Dent J 2006;201:527-34.
15. Willhite C, Bellerino M, Eubank J. Treatment of congenitally missing lateral incisors with resin-bonded fixed partial dentures. Quintessence Dent Technol 2002;25:63-72.
16. Shillingburg HT, Hobo S, Whitsett LD, Jacobi R, Brackett SE. Fundamentals of Fixed Prosthodontics. 3rd ed. Chicago: Quintessence; 1997. p. 88.
17. Yokoyama D, Shinya A, Lassila LV, Gomi H, Nakasone Y, Vallittu PK, *et al.* Framework design of an anterior fiber-reinforced hybrid composite fixed partial denture: A 3D finite element study. Int J Prosthodont 2009;22:405-12.
18. Miettinen M, Millar BJ. A review of the success and failure characteristics of resin-bonded bridges. Br Dent J 2013;215:E3.
19. Kelly JR. Clinically relevant approach to failure testing of all-ceramic restorations. J Prosthet Dent 1999;81:652-61.
20. Aktas G, Basara EG, Sahin E, Uctasli S, Vallittu PK, Lassila LV, *et al.* Effects of different cavity designs on fracture load of fiber-reinforced adhesive fixed dental prostheses in the anterior region. J Adhes Dent 2013;15:131-5.
21. Vallittu PK, Kononen M. Biomechanical aspects and material properties. In: Karlsson S, Nilner K, Dahl BL, editors. A Textbook of Fixed Prosthodontics: The Scandinavian Approach. Stockholm: Gothia; 2000.
22. Assunção WG, Barão VA, Tabata LF, Gomes EA, Delben JA, dos Santos PH, *et al.* Biomechanics studies in dentistry: Bioengineering applied in oral implantology. J Craniofac Surg 2009;20:1173-7.
23. Shinya A, Yokoyama D, Lassila LV, Shinya A, Vallittu PK. Three-dimensional finite element analysis of metal and FRC adhesive fixed dental prostheses. J Adhes Dent 2008;10:365-71.