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Original Research Article

Evaluation of the Bond Strength of Restorative Materials Applied to Base Materials and Pulp Capping Agents Using Different Techniques: An *In-Vitro* Study

Farklı Tekniklerle Uygulanan Restoratif Materyallerin Kaide Materyallerine ve Pulpa Kapaklama Ajanlarına Bağlanma Dayanımının Değerlendirilmesi: Bir İn-Vitro Çalışma

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ABSTRACT

Aim: To evaluate the shear bond strength (SBS) of restorative materials applied to base materials and pulp capping agents using different techniques *in-vitro*.

Materials and Method: A total of 80 acrylic blocks were obtained. Either Fuji II LC (FLC) or Biodentine (BD) was applied to the cavities opened in the center of the acrylic blocks. Thereafter, EverX Posterior (EXP) and Fuji IX (FIX) were used in a transparent plastic tube in accordance with the manufacturer's instructions in one group and placed after pre-heating in another group (n=10). Then the SBS test was performed. Three-way ANOVA test was used to evaluate the effect of base material/pulp capping agent, restorative material and application technique on SBS. One-way ANOVA test was used for comparisons of individual parameters between groups in application techniques. Tamhane's T2 test was used to determine the group causing the difference. Chi-square test, Fisher's Exact test, Fisher Freeman Halton Exact Chi-square test and Yates continuity correction were used to compare qualitative data. Significance was evaluated at $p<0.05$ level.

Results: After pre-heating, the SBS values of EXP to BD (6.4±3.0 MPa) was significantly greater than that of FIX (1.2±0.4 MPa) ($p<0.05$). When FLC material was used, the SBS values of EXP material were found to be higher than FIX material, regardless of the application technique.

Conclusion: When a base material containing resin is used, it can be concluded that using a composite resin restorative material is more appropriate in terms of obtaining higher SBS values.

Keywords: Biodentine; Fiber; Glass ionomer; Pre-heating; Shear bond strength

ÖZET

Amaç: Bu çalışmanın amacı, farklı tekniklerle uygulanan restoratif materyallerin kaide materyallerine ve pulpa kapaklama ajanlarına makaslama bağlanma dayanımının (SBS) *in-vitro* olarak değerlendirilmesidir.

Gereç ve Yöntem: Toplam 80 adet akrilik blok elde edildi. Akrilik blokların ortasına açılan kavitelere Fuji II LC (FLC) veya Biodentine (BD) uygulandı. Daha sonra, EverX Posterior (EXP) ve Fuji IX (FIX) şeffaf plastik bir tüp kullanılarak; bir grupta üretici firmanın talimatlarına uygun olarak, diğer grupta ise ön ısıtma uygulandıktan sonra yerleştirildi (n=10). Ardından SBS testi gerçekleştirildi. Kaide materyali/pulpa kapaklama ajanı, restoratif materyal ve uygulama tekniğinin bağlanma dayanımı üzerindeki etkisinin değerlendirilmesinde Üç-yollu ANOVA testi kullanıldı. Uygulama tekniklerinde ayrı ayrı parametrelerin gruplar arası karşılaştırılmalarında tek-yollu ANOVA testi kullanıldı. Farka neden olan grubun belirlenmesinde Tamhane's T2 testi kullanıldı. Niteliksel verilerin karşılaştırılmasında ise Ki-Kare testi, Fisher's Exact Ki-Kare testi, Fisher Freeman Halton Exact Ki-kare testi ve Yates düzeltmesi kullanıldı. Anlamlılık $p<0.05$ düzeyinde değerlendirildi.

Bulgular: Ön ısıtmadan sonra EXP'nin BD'ye (6.4±3.0 MPa) olan SBS değerleri, FIX'in (1.2±0.4 MPa) bağlanma dayanımından önemli ölçüde daha yüksekti ($p<0.05$). FLC malzemesi kullanıldığında, uygulama tekniğinden bağımsız olarak EXP malzemesinin SBS değerlerinin FIX malzemesine göre daha yüksek olduğu bulundu.

Sonuç: Rezin içeren bir kaide materyali kullanıldığında, daha yüksek SBS değerleri elde etmek açısından kompozit rezin restoratif materyal kullanılmasının daha uygun olduğu sonucuna varılabilir.

Anahtar Kelimeler: Biodentine; Fiber; Cam iyonomer; Ön ısıtma; Makaslama bağlanma dayanımı

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INTRODUCTION

The mechanical and physical characteristics of composite resins can be enhanced through a variety of applications. Fiber-reinforced composite resins are an example of this application. Introduced for use as a reinforcing base for large restorations, these materials have material structure-strengthening properties such as inhibition of crack propagation owing to the incorporation of versatile short glass fibers into the resin matrix.[1] Fiber reinforcement technology has become an option for increasing the fracture strength and mechanical properties of particle-filled composite resins and has increased the use of composite resin materials for large restorations of stress-bearing posterior teeth. The aim of fiber reinforcement is to make the structurally affected tooth more durable internally and prevent fractures.[2]

Wilson and Kent[3] introduced glass ionomer cements to dentistry in 1972. The particle size of the material varies by manufacturer, but sizes generally range from 20 μm for adhesive forms to 50 μm for restorative forms. High-viscosity glass ionomer cements have been developed to increase the wear resistance of conventional glass ionomer cements, strengthen their low mechanical properties, and increase their indications that are limited to class I and V restorations. These cements are considered as an alternative to amalgam and resin composites as permanent restorative materials. They are produced in the form of capsules because manual mixing and adjustment of the correct powder–liquid ratios are difficult. Standard and high powder–liquid-ratio materials have advantages such as ease of use, convenience, and homogeneous consistency.[4]

The use of different techniques in applying restorative materials has recently become more feasible. Initially, restorative materials are placed in cavities after pre-heating. Pre-heating the composite resins before the polymerization process has gained popularity among dentists as a way to improve the manipulation properties of the material during its insertion into the cavity.[5] Pre-heating before photo-activation reduces the viscosity of composites, which has been shown to improve the marginal adaptation of the material and reduce microleakage due to increased adaptation to the cavity walls.[6] In addition, increasing the polymerization temperature increases the mobility of both radicals and monomers, resulting in a higher rate of polymerization. This approach can improve physical and mechanical properties such as higher surface hardness and increased diametral tensile strength and flexural strength of composite resins.[7] However, it has been reported that heat application increases the microshear bond strength of composite resins to the dentin.[8]

The pre-heating applied to composite resins can also be applied to glass ionomer restorative materials. Heat curing is a relatively new technique that uses radiant heat to accelerate the curing reaction of traditional glass ionomer cements. This technique helps overcome the early moisture sensitivity problem of glass ionomer cements. Some studies have investigated the effects of thermo-setting on the mechanical properties of various glass ionomer cements and reported an increase in surface microhardness and flexural strength.[9] Researchers have stated that heat treatment increases the mobility of both polymer segments and reactive free radicals formed during polymerization, which increases the degree of conversion of monomers to polymers and allows the cross-linking of polymers to increase.[10] To date, limited studies have evaluated the bond strength of pre-heated glass ionomer cements.[11-14]

Vital pulp treatments aim to preserve the vitality of the pulp by directly covering the pulp tissue exposed for various reasons or specifically by providing tertiary dentin formation with capping material applied on the exposed pulp tissue.[15] Various calcium silicate-based cements can be used as pulp capping material. One of them is Biodentine, a pulp capping material containing bioactive calcium silicate. Biodentine has been developed as a new tricalcium silicate-based inorganic restorative cement.[16] The most important advantages of Biodentine over mineral trioxide aggregate (MTA) are its clinical ease of use, high viscosity, less color change, short setting time (12 min), and better physical properties[17] include having denser particles and less porous structures.[18] Biodentine's microhardness, bending and compressive strength values are better than calcium silicate cements, so it is thought that biodentine can be used as an alternative to glass ionomer cements in restorative dentistry.[19] Considering these advantages, the use of Biodentine in dental clinics tends to increase.

Sufficient bond strength of pulp capping agents and base materials to restorative materials is important for clinical success. The aim of this study was to evaluate the shear bond strength (SBS) of restorative materials applied to base materials and pulp capping agents using different techniques *in-vitro*.

The first null hypothesis of the study was that the placement technique would not affect the bond strength. The second null hypothesis was that the bond strength of pulp capping agents and base materials to restorative materials would not differ.

MATERIALS AND METHOD

The materials used in the study are shown in Table 1. Sample size calculations based on a 50% effect size, 80% power, and a 5% type 2 error level, suggested inclusion of at least 9 specimens in each group. Considering possible data losses, 10 specimens were planned for each group. G*Power (v. 3.1.9.6.; Franz Faul, Universitat Kiel, Germany) package program was used for specimen size calculations for all statistical analyses.

In this study, the SBS of restorative materials applied to base materials and pulp capping agents was evaluated. A chemically cured acrylic resin was mixed at the rate recommended by the manufacturer and placed in a polyvinylchloride cylinder to form the molds in which the base material and pulp capping agent will be placed. The previously prepared silicone mold with a depth of 2 mm and a diameter of 4 mm was placed in the middle of the acrylic resin. After completion of the polymerization of the acrylic resin, the silicone mold was removed with a probe. In this way, acrylic blocks containing a total of 80 cylindrical cavities were obtained. A transparent plastic tube with a diameter of 2 mm and a height of 4 mm was used to apply fiber-reinforced composite resin (EverX Posterior, GC, Tokyo, Japan) and high-viscosity glass ionomer cement (Fuji IX, GC, Tokyo, Japan) to either the base material (Fuji II LC, GC, Tokyo, Japan) or pulp capping agent (Biodentine, Septodont, St. Maur Des Fosses, Val-de-Marne, France) with universal bonding agent (G-Premio Bond, GC, Tokyo, Japan) used in self-etch mode.

The acrylic blocks were divided into two groups for base material and pulp capping agent placement. Thereafter, the blocks were divided into four subgroups according to the restorative materials to be placed on these materials using different techniques (n=10).

Table 1. Materials used in the study

Material Name	Manufacturer	Content
EverX Posterior (EXP)	GC, Tokyo, Japan	Bis-GMA, PMMA, TEGDMA, short e-glass fiber filler, barium glass (74.2% by weight, 53.6% by volume)
Fuji IX (FIX)	GC, Tokyo, Japan	Powder: Aluminosilicate glass, polyacrylic acid Liquid: Polyacrylic acid, water
G-Premio Bond	GC, Tokyo, Japan	Acetone (25-50%), 2-hydroxy-1,3 dimethacryloxypropane (10-20%), methacryloyloxydecyl dihydrogen phosphate (5-10%), 2,2-ethylenedioxydiethyl dimethacrylate (1 5%), diphenyl(2,4) ,6-trimethylbenzoyl)-phosphine oxide (1–5%), 2,6-di-tert-butyl-p-cresol (<0.5%).
Biodentine (BD)	Septodont, Saint-Maur-des-fossés, Val-de-Marne, France	Powder: Ca_3SiO_5 (> 80%), $CaCO_3$, ZrO_2 Liquid: Water, $CaCl_2$, partially modified polycarboxylate.
Fuji II LC (FLC)	GC, Tokyo, Japan	Powder: Al_2O_3-SiO_2-CaF_2 glass and HEMA urethane dimethacrylate. Liquid: Polyacrylic acid

*Abbreviations: Bis-GMA, bisphenol A glycidyl methacrylate; PMMA, polymethyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; Ca_3SiO_5, tricalcium silicate; $CaCO_3$, calcium carbonate; ZrO_2, zirconium dioxide; $CaCl_2$, calcium chloride; Al_2O_3, aluminium oxide; SiO_2, silicon dioxide; CaF_2, calcium fluoride; HEMA, hydroxyethyl methacrylate.

-Pulp capping agent (pulp capping agent with bioactive calcium silicate: Biodentine) (n=40)

- Group 1a (n=10): Control fiber-reinforced composite resin (EverX Posterior) [BD - EXP]
- Group 1b (n=10): Heat-treated fiber-reinforced composite resin (EverX Posterior) [BD - EXP]
- Group 2a (n=10): Control high-viscosity glass ionomer cement (Fuji IX) [BD - FIX]
- Group 2b (n=10): Heat-treated high-viscosity glass ionomer cement (Fuji IX) [BD - FIX]

-Base material (resin-modified glass ionomer cement: Fuji II LC) (n=40)

- Group 3a (n=10): Control fiber-reinforced composite resin (EverX Posterior) [FLC - EXP]
- Group 3b (n=10): Heat-treated fiber-reinforced composite resin (EverX Posterior) [FLC - EXP]
- Group 4a (n=10): Control high-viscosity glass ionomer cement (Fuji IX) [FLC - FIX]
- Group 4b (n=10): Heat-treated high-viscosity glass ionomer cement (Fuji IX) [FLC - FIX] (Table 2).

Table 2. Groups included in the study

Base Material/Pulp Capping Material	Restorative Material	Control	Heat
BD	EXP	1a	1b
BD	FIX	2a	2b
FLC	EXP	3a	3b
FLC	FIX	4a	4b

The base material and pulp capping agent were placed in cavities with a depth of 2 mm and a diameter of 4 mm in accordance with the manufacturer's instructions. The resin-modified glass ionomer cement used as the base material was polymerized using an LED light device (D-Light Pro, GC Europe N.V., Leuven, Belgium) in accordance with the manufacturer's instructions.

After the preparation of the materials, the bonding procedure of the restorative materials was carried out after polymerizing the resin-modified glass ionomer cement with light, in accordance with the manufacturer's instructions and in accordance with clinical use. In the Biodentine groups, the bonding procedure of the restorative materials was conducted after waiting 12 minutes for the Biodentine to set, in accordance with the manufacturer's instructions and in accordance with clinical use. Thereafter, universal adhesive (G- Premio Bond, GC, Tokyo, Japan) was applied to the surface of the base material and pulp capping agent in groups 1a and 3a in accordance with the manufacturer's instructions. After 10 s, it was dried for 5 s and polymerized for 10 s using the LED light device. The fiber-reinforced composite resin was placed on the adhesive-applied specimen surfaces using a 2-mm-diameter and 2-mm-depth high transparent plastic tube in accordance with the manufacturer's instructions and polymerized using the LED light device. In groups 2a and 4a, a cavity surface conditioner (Cavity Conditioner, GC, Tokyo, Japan) was applied to the surface of the base material and pulp capping agent for 10 s in accordance with the manufacturer's instructions, rinsed with water, and dried gently with air pressure. High-viscosity glass ionomer cement (Fuji IX, GC, Tokyo, Japan) was mixed in the amalgamator (Linea Tac, Montegrosso, Italy) for 10 seconds in accordance with the manufacturer's instructions, and then bonding to the base material and pulp capping agent using a transparent plastic tube with a diameter of 2 mm and a height of 4 mm. In groups 1b, 2b, 3b, and 4b, the restorative materials were placed on the base material and pulp capping agent using a transparent plastic tube after being kept in water at 50°C (the temperature of the water was kept constant with the help of a thermocouple). The specimens in groups 1b and 3b were polymerized using the LED light device.

The prepared specimens were kept in the oven at 37°C for 24 h. The bond strength test was performed using a universal testing device (Schimadzu IG-IS, Kyoto, Japan) under 1 mm/min head speed until fracture occurred. The values obtained in Newton were divided by the bonding surface area of the materials and converted into megapascals. The fracture surface areas of the specimens were examined using a stereomicroscope (Olympus SZ-40, Tokyo, Japan) at 40× magnification. The fracture types were determined according to the following classification, and the data obtained were recorded.

- Adhesive Fracture: 75% or more of the fracture is between the base/pulp capping material and the restorative material.
- Cohesive Fracture from Base/Pulp Capping Ma-

terial: 75% and more of the breakage is in the base/pulp capping material itself.

- Cohesive Fracture from Restorative Material: 75% and more of the fracture is in the restorative material itself.
- Mix Fracture: Mixed failure is observed between the base/pulp capping material-adhesive-restorative material.

Statistical Analysis

IBM SPSS version 22 was used for statistical analysis. The conformity of data distribution to normal distribution was evaluated using the Shapiro-Wilk test. Three-way ANOVA was used to evaluate the effect of base material (FLC)/pulp capping agent (BD), restorative material (EXP-FIX) and application technique (control-heat) on bond strength. For application technique (control-heat), one-way ANOVA was used to compare individual parameters between groups and Grawes-Howell test was used to determine the groups of base material (FLC)/pulp capping agent (BD) or restorative material (EXP-FIX) that caused the difference. Chi-square test of independence was used to compare qualitative data. Significance was evaluated at p<0.05.

RESULTS

The Shapiro-Wilk test revealed that the parameters had a normal distribution.

According to the three-way ANOVA results; There was a statistically significant difference in bond strengths between the base materials (p:0.001; p<0.05). There was a statistically significant difference in bond strengths between the restorative materials (p:0.001; p<0.05). There is no statistically significant difference in bond strengths between the application techniques (p:0.53; p>0.05). The joint effect of the base material and restorative material on bond strength was statistically significant (p:0.001; p<0.05). The joint effect of the base material and application technique on bond strength was not statistically significant (p:0.16; p>0.05). The joint effect of the restorative material and application technique on bond strength reached statistical significance (p:0.016; p<0.05). The joint effect of the base material, restorative material and application technique on bond strength was not statistically significant (p:0.13; p>0.05) (Table 3).

In control groups (Groups 1a, 2a, 3a, and 4a); A statistically significant difference was found between the groups in terms of bond strength (p<0.001 p<0.05). The post-hoc Grawes-Howell test conducted to determine which groups the significance originated from revealed that the bond strength of Group 3a was higher (p<0.05) than Group 1a (p=0.002), Group 2a (p=0.002) and Group 4a (p<0.001). The bond strength of Group 4a was significantly lower (p<0.05) than Group 1a (p<0.001), Group 2a (p=0.013) and Group 3a (p<0.001). There was no significant difference between Group 1a and Group 2a (p>0.05) (Table 4, Figure 1).

In groups where heat was applied (Groups 1b, 2b, 3b, and 4b); A statistically significant difference was found between the groups in terms of bond strength (p<0.001; p<0.05). The post-hoc Grawes-Howell test conducted to determine which groups the significance originates from showed that the bond strength of Group 3b was higher (p<0.05) than Group 1b (p=0.007), Group 2b (p<0.001) and Group

Table 3. Three-way ANOVA test evaluation results

Bond Strength	Type III Sum of Squares	df	Mean Square	F	p
Base material	93.49	1	93.49	12.93	0.001*
Restorative material	1064.34	1	1064.34	147.27	0.001*
Application technique	2.82	1	2.82	0.39	0.53
Base material * Restorative material	397.21	1	397.21	54.96	0.001*
Base material * Application technique	14.45	1	14.45	2.00	0.16
Restorative material * Application technique	43.99	1	43.99	6.09	0.016*
Base material * Restorative material * Application technique	16.76	1	16.76	2.32	0.13

Three-Way ANOVA Test *p<0.05

Table 4. Evaluation of bond strength according to base material and restorative material separately in application techniques

	Bond Strength	
	Control (a)	Heat (b)
	MPa (Mean±SD)	MPa (Mean±SD)
Biodentine-EverX Posterior (Group 1)	5.27±1.27^{A}	6.44±2.96^{A}
Biodentine- Fuji IX (Group 2)	4.83±3.18^{A}	1.21±0.42^{B}
Fuji II LC -EverX Posterior (Group 3)	11.95±4.05^{B}	13.0±4.50^{C}
Fuji II LC-Fuji IX (Group 4)	0.77±0.58^{C}	0.68±0.35^{D}
F:	30.15	44.8
df	3	3
p	<0.001*	<0.001*

One way ANOVA Test *p<0.05
Different capital letters in the columns indicate differences between groups.

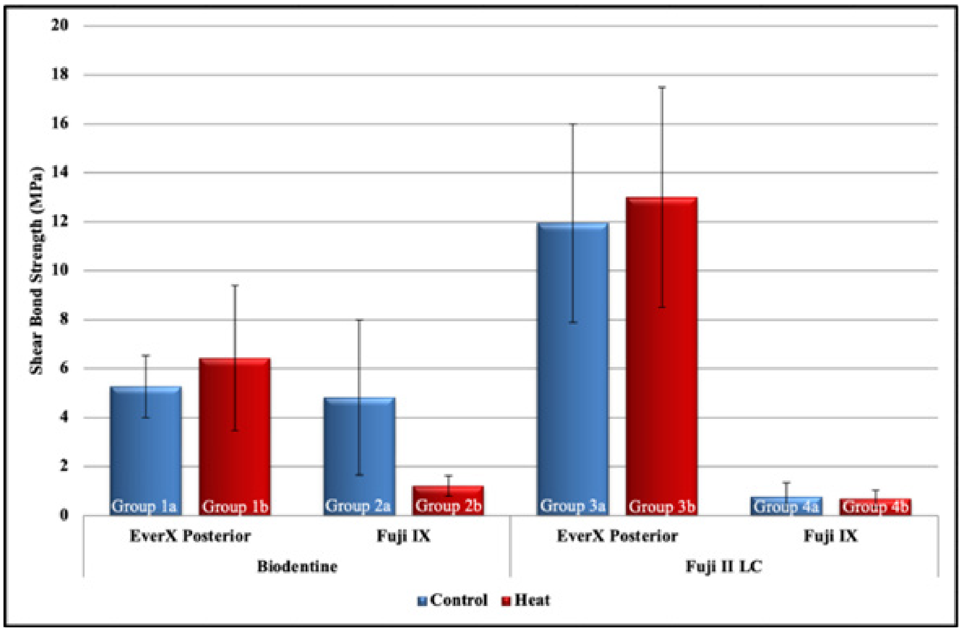

Figure 1. Shear bond strength values by groups

4b (p<0.001). The bond strength of Group 4b was found to be significantly lower (p<0.05) than Group 1b (p=0.001), Group 2b (p=0.033) and Group 3b (p<0.001). The bond strength of Group 1b was significantly higher than Group 2b (p=0.001; p<0.05) (Table 4, Figure 1).

To summarize briefly:

After pre-heating, the bond strength of EXP to BD (6.5±3.0 MPa) was significantly greater than that of FIX (1.2±0.4 MPa) (p<0.05). When BD and FIX were used, the bond strength without pre-heating (4.8±3.2 MPa) was statistically significantly higher than when pre-heating was performed (1.2±0.4 MPa) (p<0.05). When FLC material was used and no pre-heating was applied; the bond strength of EXP (12.0±4.1 MPa) was statistically significantly higher than that of the FIX (0.8±0.6 MPa) (p<0.05). When FLC and FIX are used; there was no statistically significant difference in terms of bond strength between the application techniques (p>0.05). When FLC material was used, the bond strength values of EXP material were found to be higher than FIX material, regardless of the application technique.

Table 5. Separate evaluation of fracture types according to base material and restoration material in application techniques

	Fracture Type	**Biodentine-EverX Posterior (Group 1)**	**Biodentine-Fuji IX (Group 2)**	**Fuji II LC -EverX Posterior (Group 3)**	**Fuji II LC-Fuji IX (Group 4)**	
		n (%)	**n (%)**	**n (%)**	**n (%)**	**p**
Control (a)	Cohesive Fracture from Base	0 (0)	2 (20)	0 (0)	0 (0)	χ^2:24.245 df:6 p<0.001
	Cohesive Fracture from Restoration	2 (20)	0 (0)	7 (70)	0 (0)	
	Adhesive Fracture	8 (80)	8 (80)	3 (30)	10 (100)	
Heat (b)	Cohesive Fracture from Base	1 (10)	1 (10)	0 (0)	0 (0)	χ^2:11.54 df:6 p:0.073
	Cohesive Fracture from Restoration	0 (0)	0 (0)	3 (30)	0 (0)	
	Adhesive Fracture	9 (90)	9 (90)	7 (70)	10 (100)	

Pearson Chi-Square Test *p<0.05

Considering the fracture types, the group in which the cohesive fracture from the restoration was statistically significant was group 3a, wherein EverX Posterior was applied on Fuji II LC without heating (p<0.05) (Table 5).

DISCUSSION

This study demonstrated that heating affected the bond strength of the glass ionomer-based restorative material, so the first null hypothesis was rejected. Further, the bond strength of the fiber-reinforced composite resin was greater in all groups than that of the glass ionomer-based restorative material. Consequently, the second null hypothesis was also invalidated.

Sometimes, it is not easy for clinicians to predict the prognosis when the pulp becomes exposed in the tooth to be restored. Therefore, researchers are attempting to find ways to preserve the vitality of the pulp using biocompatible materials such as calcium silicate-based cement, which provides a strong barrier against microleakage. Biodentine is a new calcium silicate-based pulp capping agent that sets faster and has improved mechanical properties compared with MTA. After pulp capping, the treated tooth needs a suitable final restoration, for which glass ionomer-based materials or composite resins are commonly used.[20] Therefore, in addition to the bioactivity, biocompatibility, and remineralization properties of pulp capping agents, their bond strength to restorative materials is also an important factor. Proper bonding of composite resins to pulp capping agents ensures that the stress that may affect the bonding interface is spread relatively evenly.[21]

Glass ionomer cements have been widely used as base materials under composite resins since the introduction of the sandwich technique by McLean *et al*.[22] Recently, high-viscosity glass ionomer restorative materials have been developed to increase the wear resistance of conventional glass ionomer cements, strengthen their low mechanical properties, and increase their indications limited to class I and V restorations.[4] Thus today, resin-containing materials have become more questionable due to the fact that current glass ionomer cements show physical and mechanical properties comparable to dental amalgam in posterior teeth and the increasing biocompatibility concerns in the dental community in general. For this reason, the popularity of glass ionomer cements is increasing.[23] In addition, the potential for fluoride release to dental tissues, along with biological and chemical compatibility, has made glass ionomer cements a special group of materials in terms of caries prevention.[24] Fuji IX, a high-viscosity glass ionomer restorative material that can be used as a permanent restorative material in children, especially owing to its fluoride release feature, and in restorative procedures applied in adults owing to its advanced physical and mechanical properties, was preferred in this study.

Composite resins are the most frequently preferred restorative materials by dentists. Researchers have developed fiber-reinforced composite resin materials to increase the retention time and clinical success of conventional particle-filled composite resins for large restorations in posterior regions.[2] Restorative materials can be applied to dental tissues using different techniques. One of these techniques is heating such materials.

Many studies have revealed that heating reduces the viscosity of composite resins, increases the microhardness and degree of monomer conversion, and improves marginal adaptation in direct and indirect restorations.[25] In this study, the aim was to evaluate the effect of heating on the bond strength of restorative materials to pulp capping agents and base materials. EverX Posterior showed better adhesion to Fuji II LC than to Biodentine in both the control and heated groups. The bond strength between Biodentine and RMGIC and composite resin depends on the physicochemical properties and the nature of the bond between these materials. In the *in-vitro* study by Deepa *et al*.[26], it was observed that the bond strength of RMGIC to composite resin was greater than that to Biodentine, consistent with our results. RMGIC is photo-activated and shows early cohesion resistance owing to this photo-activation. In addition, the reason why the bond strength of composite resin and RMGIC is greater may be that they have a similar resin chemistry that supports chemical bonding between them. Hydroxyethyl methacrylate (HEMA), included in the RMGIC structure, forms a chemical bond with composite resin. In addition, the resin-containing adhesive agent forms a strong bonding interface by chemically bonding to both composite resin and RMGIC.[26] In the meta-analysis of Manoj *et al*.[27], it was reported that the bond strength of composite resin to RMGIC was higher than Biodentine, MTA and TheraCal LC. RMGIC has been reported to be chemically bonded to the resin composite by copolymerization of the unreacted monomer (HEMA) contained in the oxygen inhibition layer formed on the outer surface of the cured RMGIC with adhesive systems or composite resins. One reason for the lower bond strength of Biodentine to composite resin may be the low bond strength of immature Biodentine material in the early setting stage. A period of at least two weeks is needed for the crystalline structure of Biodentine to accurately form and reach sufficient strength to withstand polymerization stresses.[18] However, the manufacturer states that the restorative material can be applied after the material has a setting time of 12 minutes. Therefore, this study was designed according to the procedure routinely applied in the clinic.

Unlike resin-containing materials, heated glass ionomer cements show increased viscosity. Heating may increase the rate of ion diffusion, speed up the reaction, and reduce the working time and setting time. However, after the GIC is mixed, heat improves the physical and chemical properties of the material.[28] In the present study, the bond strength to Biodentine decreased when pre-heating was applied to the high-viscosity glass ionomer restorative material. Pre-heating of glass ionomer materials is known to reduce both the curing time and working time.[28] Based on our findings, it may be that the decrease in the bond strength of the high-viscosity glass ionomer restorative material to Biodentine after pre-heating is caused by the insufficient bonding due to the earlier completion of the curing reaction.

In our study, low bond strength values were observed between the RMGIC and the high-viscosity glass ionomer restorative material regardless of the application technique. To our knowledge, no study has yet evaluated the bonding of two different glass ionomers. Conventional glass ionomer cement consists of powder and liquid. Aluminum, silicon, and calcium are the three primary constituents of the glass particle. Aluminum oxide and silicon dioxide form the skeleton of the glass. This material has a tetrahedral structure with a three-dimensional silicate structure. In general, zinc oxide and strontium oxide replace calcium oxide.[4] Hydrophilic monomers and polymers such as HEMA have been added to the chemical structure of resin-modified glass ionomer cements to strengthen the mechanical properties of the material.[29] This difference in chemical structure may prevent adhesion between the two materials.

Heating of resin-containing materials increases the conversion rate of monomers to polymers and the surface microhardness value without accelerating the time at which maximum polymerization is achieved. This improvement is probably attributed to the increased molecular mobility and collision frequency of reactive molecules. In the study by Covey *et al*.[10], the effect of heat application on the diametral tensile strength of composite resins was evaluated, and it was noted that heating had a positive effect on the diametral tensile strength. The researchers stated that heating composite resins minimized tooth–restoration interface stresses and marginal cavity formation caused by polymerization shrinkage. In this study, it was observed that heating EverX Posterior did not cause a significant change in the bond strength when the same base material or pulp capping agent was used. After the composite resin specimens were prepared, they were kept in the oven at 120°C for 7 min. The difference in the results of the study may be attributed to the difference in the amount of heat applied and the time and procedure of heating after the material polymerized. In addition, a fiber-containing composite resin was used in our study. The addition of fiber to the composite resin structure can also affect the bond strength of the material, as it can change the viscosity. Therefore, the difference in the results from the related study may be attributed to the differences in the structure of the restorative materials and adhesives used.

This study has some limitations due to the nature of *in-vitro* research. The limitation of this study is that no aging procedure was applied, which may affect the long-term bonding success of restorative materials after clinical application. Although this study does not include this procedure, it is among the limited number of studies evaluating the bond strength of restorative materials applied with different techniques to the base material and pulp capping agents.

CONCLUSIONS

Within the limitations of the current study, it was concluded that: Heating affects the bond strength of fiber-reinforced composite resins.

Heating fiber-reinforced composite resins can positively affect the bond strength to bioactive calcium silicate pulp capping agent.

Light-cured base materials can be used owing to their greater bond strength to fiber-reinforced composite resins.

Heating of glass ionomer-based restorative materials may reduce their bond strength.

The use of light-cured glass ionomer base materials under glass ionomer-based restorative materials may not be appropriate owing to their low bond strength values.

Considering the results obtained from this study; heating of fiber-reinforced composite resins before the restorative procedure can be recommended because it can positively affect the bond strength of the material to the underlying bioactive calcium silicate pulp-capping agent. In addition, if a restoration with a fiber-reinforced composite resin is planned, it is recommended that the base material be a light-cured based materials in order to obtain better bond strength. However, if a restoration is planned with a glass ionomer-based material, we do not recommend preheating as it negatively affects the bond strength of the material.

CONFLICTS OF INTEREST STATEMENT

The authors report no conflicts of interest to declare.

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