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Comparison of a Self-Adhesive Resin Cement, a Conventional and a Bulk-Fill Resin Composite for Luting of Indirect Restorative Materials; the Effect of Thickness and Material Factors on Translucence, Monomer Conversion and Resin-Dentin Bond Strength

Sezer Demirbuga[1-a], Hacer Balkaya[1-b*], Aysun Tugce Akay[2-c]

[1] *Department of Restorative Dentistry, Erciyes University Faculty of Dentistry, Turkiye.*
[2] *Department of Restorative Dentistry, Kütahya Health Sciences University Faculty of Dentistry, Kütahya, Turkiye.*

**Corresponding author*

Research Article

History

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ABSTRACT

Introduction: In tis study, it was aimed to determine the effect of thickness and material factors on monomer conversion, translucency, and resin-dentin bond strength in luting indirect restorative materials (IRM) of different thicknesses using a resin cement, a conventional and a bulk-fill resin composite.

Materials and methods: Samples of lithium disilicate glass-ceramic material (IPS e.max) and ceramic-resin hybrid material (Lava Ultimate) in 2 and 4 mm thicknesses, were luted using RelyX U200 (a self-adhesive resin cement), X-tra fil (a bulk-fill resin composite) and Z250 (a conventional microhybride resin composite) to the dentin surface and subjected to bond strength test after thermal cycle. In addition, the translucency parameter (TP) of the prepared blocks and the degree of conversion (DC) of the luting materials were investigated. The data was statistically analyzed.

Results: The bond strength of X-tra fil and Z250 was statistically higher than RelyX U200 ($p<0.05$). Thickness (2mm vs 4mm) and material factor (E.max vs Lava) did not change the bond strength ($p>0.05$). The increase in thickness decreased the TP of IRMs and the DC of resins underlying Lava ($p<0.05$). The material factor did not affect TP and DC ($p>0.05$).

Conclusion: Conventional and bulk-fill resin composites can be alternative luting materials to resin cements. Thickness increase did not change bond strength, while decreased TP, and DC only for Lava Ultimate.

Keywords: Bond strength; Indirect restorative material; Luting agent; Monomer conversion; Thickness; Translucency.

İndirekt Restoratif Materyallerin Yapıştırılmasında Bir Self-Adeziv Rezin Siman, Bir Geleneksel ve Bir Bulk-Fil Rezin Kompozitin Karşılaştırılması; Kalınlık ve Materyal Faktörlerinin Şeffaflık, Monomer Dönüşümü ve Rezin-Dentin Bağlanma Dayanımı Üzerine Etkisi

Research Article

Süreç

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ÖZ

Amaç: Bu çalışmada farklı kalınlıklardaki indirekt restoratif materyallerin (IRM) simantasyonunda kullanılan bir rezin simanı, bir geleneksel ve bir bulk-fil kompozit rezinin dentin bağlanma dayanımı ve monomer dönüşümü üzerine materyal kalınlığı, şeffaflık ve materyal tipi faktörlerinin etkisini belirlemek amaçlanmıştır.

Gereç ve yöntemler: İki farklı kalınlıktaki (2 mm ve 4 mm) lityum disilikat cam-seramik materyal (IPS e.max) ve seramik-rezin hibrit materyal (Lava Ultimate) örnekleri, dentin yüzeyine RelyX U200 (bir self-adeziv rezin siman), X-tra fil (bir bulk-fil rezin kompozit) ve Z250 (bir geleneksel mikrohibrit rezin kompozit) kullanılarak yapıştırılmıştır ve termal döngü uygulaması sonrası bağlanma dayanım testine tabi tutulmuştur. Ayrıca, hazırlanan blokların şeffaflık parametresi (TP) ve yapıştırma materyallerinin monomer dönüşüm derecesi (DC) araştırılmıştır. Elde edilen veriler istatistiksel olarak analiz edilmiştir.

Bulgular: X-tra fil ve Z250'nin bağlanma dayanımları istatistiksel olarak RelyX U200'den anlamlı derecede daha yüksekti ($p<0,05$). Kalınlık (2 mm'ye karşı 4 mm) ve malzeme faktörünün (E.max'a karşı Lava), bağlanma dayanımını anlamlı derecede değiştirmediği bulunmuştur ($p>0,05$). Kalınlığın artması, IRM'lerin TP'sini ve altında bulunan rezinlerin DC'sini azaltmıştır ($p<0,05$). Malzeme faktörü, TP ve DC'yi etkilememiştir ($p>0,05$).

Sonuç: Geleneksel ve bulk-fil rezin kompozitler, rezin simanlara alternatif yapıştırma materyali olarak kullanılabilir. Kalınlık artışı bağlanma dayanımını değiştirmezken, sadece Lava Ultimate için TP ve DC'yi azaltmıştır.

Anahtar kelimeler: Bağ kuvveti; İndirekt restoratif materyal; Yapıştırma ajanı; Monomer dönüşümü; Kalınlık; Şeffaflık.

[a] sezerdemirbuga@hotmail.com https://orcid.org/0000-0003-1028-9461 [b] dhacer89@hotmail.com https://orcid.org/0000-0002-6704-0774
[c] aysuntugceakay@hotmail.com https://orcid.org/0000-0003-1028-9461

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Introduction

Dental restorations can be performed using two methods including direct or indirect. Indirect restorations have some advantages compared to direct method that is finished in the mouth in one session. Since the layering processes are skipped, shrinkage during polymerization of each layer is eliminated.[1] Finishing and polishing procedures, and reconstruction of the occlusal anatomy are realized more ideally, so the restorations which is more esthetic, and in which plaque control is easy can be achieved. More functional restorations can be obtained, especially in teeth with excessive tissue loss, since optimum contact relations with adjacent teeth and ideal occlusal relations with opposite teeth are provided.[1,2] In addition, more ideal polymerization and less residual monomer release can be achieved with additional polymerization techniques (such as heat, pressure or light).[1,3,4]

The success of indirect restorations depends on various factors, including material selection. Ceramic, hybrid, and resin composites are commonly used as indirect restorative materials (IRM).[1,2,5] All-ceramic materials have high esthetic properties, but processing and repairing of these materials are quite difficult. Moreover, due to their high elastic modulus, they can cause fractures in themselves and the remaining tooth tissues with the wedge effect and wear on the opposite tooth.[2,5] On the other hand, resin materials have some deficiencies such as low abrasion and mechanical strength, water absorbtion and discoloration, and their esthetic properties are not as good as ceramics. For this reason, hybrid materials were developed to take advantages of both materials.[2]

The selected luting material is another factor affecting the success of indirect restorations. Resin cements and resin composites are frequently used for this purpose nowadays.[6-8] Due to the discoloration of resin cements over time, insufficient mechanical properties and inability to fill the possible micro-macro gaps between the restoration and tooth tissue because of their viscosity, many practitioners prefer to lute the indirect restorations with traditional composite resins. However, in cases that the restoration and the underlying luting agent have a thick layer, the polymerization of the resin composite is compromised. Therefore, it may be advantageous to use a bulk-fill composite resin with better light transmittance instead of conventional composite resin as a luting material.[9]

The thickness of restorative materials also affects success.[10] When performing an indirect restoration in the posterior region, the vertical depth in all regions of the cavities is often not the same. For this reason, while the IRM used is shaped thicker in some regions, it is formed thinly in some regions. Even if the light curing is applied from all surfaces of the tooth, there may always be areas where the light cannot reach, especially in the central part of the base of the restoration or in the gingival step regions, which are far from the light device. When high-thickness restorations such as endocrowns are required, the properties of the luting material such as hardness, elastic modulus, flexural strength, monomer release, polymerization and bond strength may be compromised by preventing the light to reach the luting agent under the IRM.[10-12] Although ceramic and hybrid materials can allow light transmission due to their glass content, optimal restoration thickness for light transmission is not extensively studied.[10,13]

In the present study, it was aimed to investigate the parameters of the restorative material type, restorative material thickness and luting material that affect the bond strength of indirect restorations. In the literature, resin cements were mostly preferred in studies testing the bond strength of the IRMs, and the information about how these materials will behave when conventional and bulk-fill composites are used for cementation is insufficient. Additionally, few studies evaluate the effect of thickness on polymerization and bond strength of luting agents. Therefore, this study tested the bond strengths and polymerization levels of different thicknesses of IPS e.max (a lithium-disilicate ceramic block) and Lava Ultimate (a hybrid material) using self-adhesive resin cement, conventional microhybrid resin composite, and bulk-fill resin composite as luting materials.

Materials and Methods

Preparation of teeth

In this study, 144 caries-free human lower third molarteeth were used. The teeth were kept in 0.5% chloramine T solution at 4 ^{o}C for a week following extraction for disinfection. The samples were then stored in distilled water at 37 ^{o}C until use. Each tooth was embedded in a self-cure acrylic resin using standard cylindrical molds up to 2 mm below the cemento-enamel junction. The occlusal enamel portions of the teeth were removed using a low speed cutting device (Isomet 1000, Buehler, Lake Bluff, IL, USA) under water cooling. The tooth surfaces were examined under a stereomicroscope (DV 4; Zeiss, Jena, Germany) at 25X magnification to check whether the enamel tissue exist or not. Then the tooth surfaces were grounded using silicon carbide papers of 400, 600 and 800 grit, respectively, to form a standard smear layer.

Preparation of the ceramic and hybrid blocks

Two different CAD-CAM restoration materials, resin nano-ceramic (Lava Ultimate, 3M ESPE, St. Paul, MN, USA) and lithium disilicate ceramic (IPS e.max, Ivoclar Vivadent AG, Schaan, Liechtenstein), were used in the present study. Prism-shaped samples of 3mmx3mmx2mm and 3mmx3mmx4mm dimensions were obtained from each block by using a cutting device (Struers Minitom, Struers, Copenhagen, Denmark) under water cooling. All surfaces of the samples were grounded with 600 and 800 grit sandpaper to eliminate surface irregularities. Then, the outer (oral) surfaces of the samples were subjected to additional polishing with a 1200 grit sandpaper. Glazing

and sintering procedures of all samples were performed by the same technician in accordance with the manufacturer's instructions.

Determination of the experimental groups

All materials used in this study, their manufacturers, contents, and batch numbers are given in Table 1. IPS E. max and Lava Ultimate blocks (2 mm and 4 mm) were luted with the following materials;

1. X-tra fil bulk-fill composite (VOCO, Cuxhaven, Germany).
2. Filtek Z250 micro-hybrid composite (3M ESPE, St. Paul, MN, USA).
3. RelyX U200 self-adhesive resin cement (3M ESPE, St. Paul, MN, USA).

Table 1. Manufacturers, types, compositions, and batch numbers of the materials used in this study.

MATERIALS	TYPE	COMPOSITIONS	Batch
Lava Ultimate (3M ESPE, St. Paul, MN, USA)	Resin nano-ceramic	80% nanoceramic (SiO_2 (20 nm), ZrO_2 (4-11 nm)), and 20% resin matrix (Bis-GMA, UDMA, Bis-EMA, TEGDMA)	N842170
IPS e.max CAD (Ivoclar Vivadent AG, Liechtenstein)	Lithium disilicate ceramic	57%-80% SiO_2, 11%-19% Li_2O, 0%-13% K_2O, 0%-11% P_2O_5, 0%-8% ZrO_2, 0%-8% ZnO, 0%-5% Al_2O_3, 0%-5% MgO, pigments	V46355
Single Bond Universal (3M ESPE, Neuss, Germany)	Universal adhesive	10-MDP phosphate monomer, Vitrebond, copolymer, HEMA, Bis-GMA, dimethacrylate resin, silane, ethanol, water.	3424447
Filtek Z250 (3M ESPE, St. Paul, MN, USA)	Microhybrid composite	Bis-GMA, Bis-EMA, TEGDMA, UDMA; 60% silica / zirconia particles	N924423
X-tra fil (Voco, Cuxhaven, Germany)	Bulk-fill composite	Inorganic fillers in a methacrylate matrix (%83.5), Bis-GMA, UDMA, TEGDMA	1717238
RelyX U200 (3M ESPE, St. Paul, MN, USA)	Self-adhesive resin cement	Organic: acidic monomers, TEGDMA, acids, dimethacrylates, photoinitiators Inorganic (%70): glass fillers, SiO_2, pigments, sodium persulfate, glass fibers,	664323
Bis-silane (Bisco, Schaumburg, IL, USA)	Silane	3-(trimethoxysilyl) propyl-2-methyl-2-propenoic acid (5-10wt%), Ethanol	A:1600007289 B:1600007290
Porcelain etch (Ultradent, South Jordan, UT, USA)	Hydrofluoric acid	%9 Hydrofluoric acid	BFBKJ

Bis-GMA, Bisphenol glycidyl methacrylate; Bis-EMA, ethoxylated bisphenol-A dimethacrylate; UDMA, urethane dimethacrylate; TEGDMA, Triethylene glycol dimethacrylate; HEMA, 2-hydroxyethyl methacrylate; MDP, Methacryloyloxidecyl dihydrogen phosphate.

Cementation procedures

- Surface preparation of the indirect restorative material

Inner surfaces of resin nano-ceramic samples were roughened with 50 µm Al_2O_3 powder for 20 s. Hydrofluoric acid (9%) was applied to both IRMs (air-abraded resin nano-ceramic surfaces and lithium disilicate ceramic surfaces) for 60 s. After the acid was washed and dried, silane was applied to the surfaces of the specimens for 30 s.

- Preparation of the tooth surface

In groups using resin composite as luting agent, a universal adhesive (Single Bond Universal, 3M ESPE, Neuss, Germany) was applied to both the tooth and specimen surfaces following the application of silane, according to the manufacturer's instructions. This procedure was not performed on the groups using RelyX U200, a self-adhesive resin cement, as luting agent.

Before the cementation procedures, a silicone frame was made to the tip of the light-curing device to prevent light scattering (Figure 1a). At the tip of the silicone, the gaps of 1.5 mm and 3.5 mm in depth (3mmx3mm) were formed in which the IRM would be placed (Figure 1b). After the surface-treated specimens were placed in the sockets on the silicone, the luting material was applied to the surfaces of the indirect restorative material, and the specimens were then placed on the tooth surface (Figures1c and 1d). After the samples were pre-polymerized for 3 s using an LED light device (Valo Cordless, 1000 mW/cm^2, Ultradent, South Jordan, UT, USA), the excessive luting materials were cleaned with a sharp scalpel (no.12). The samples were then re-polymerized for 60 s.

Thermal aging

Following the cementation of the IRMs, the samples were subjected to 5000 thermal cycles in a thermal aging device (Julabo FT 400, Julabo GmbH, Seelbach, Germany) between 5 ºC- 55 ºC (with a 30 s dwell time). In the groups in which pre-test failure was observed after the thermal cycle, new samples were prepared as much as the missing sample, and the thermal cycle procedure was also applied to these new samples.

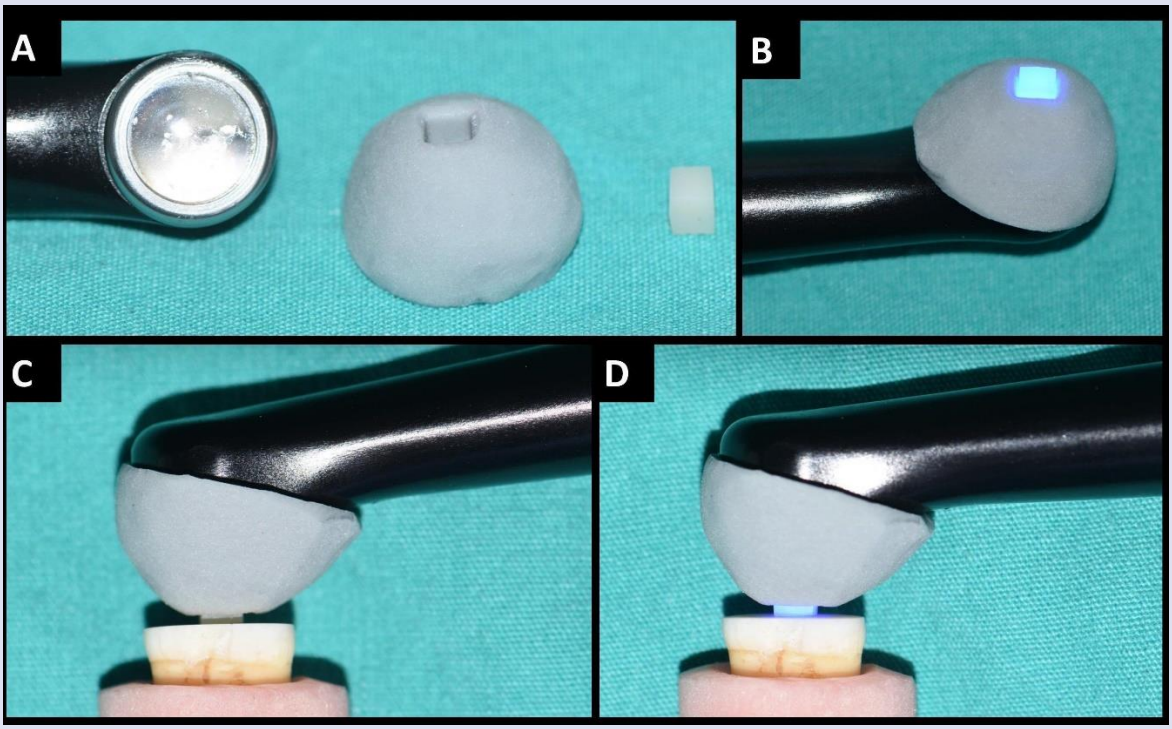

Figure 1: Modification of LED device and a simulation of application of the indirect restorative materials to the dentin surface.

Shear bond strength test

A shear bond strength test was applied to the specimens using a universal testing machine (Model 3345K7023; Instron Corp., USA). The specimens were fixed to the test device with the tooth-restoration interface perpendicular to the ground. A parallel shear force was applied to the bonding interface using a knife-edged blade with a head speed of 1 mm/min.

The maximum force at failure was recorded in Newtons (N) and the N values were converted to Megapascals (MPa) using the following formula:

Shear bond strength (MPa) = P / a^2

P is the force at break (N), and a^2 is the base area of the samples (mm^2).

The analysis of failure types

After the bond strength test, the fractured surfaces were examined with a stereomicroscope (Stemi 1000, Zeiss, Germany) under 40x magnification. The failure types were classified as adhesive failure (between the resin-block or the resin-dentin), cohesive failure (in dentin, in resin cement or within the block) and mixed failure.

Field Emission Scanning Electron Microscopy (FE-SEM)

The fractured surfaces of three samples from each group were also examined using a scanning electron microscope (FE-SEM) (GeminiSEM 500, Zeiss, Oberkochen, Germany). Before the FE-SEM analysis, the samples were fixed on an aluminum block with adhesive tape, the sample surfaces were coated with 45 A° thick Au-Pd and the surface images of the samples were taken at different magnifications (500-1500x).

Measurement of translucency values of the blocks in different thickness

Translucency measurements were realized on the 10mmx10mmx2mm and 10mmx10mmx4mm sized samples which were taken from Lava Ultimate and IPS e.max blocks (A2/LT) using a cutting device (Struers Minitom). After the finishing, polishing, sintering and glazing procedures of the samples, color measurements (L*a*b) of each sample was performed on a standard white and black background using a spectrophotometer device (Vita Easyshade compact, Vita Zahnfabrik, Bad Sackingen, Germany). Three measurements were taken from each sample and the averages were recorded. The translucency parameter (TP) was calculated with the following formula;

$$TP= [(L^*_w-L^*_b)^2 + (a^*_w-a^*_b)^2 +(b^*_w-b^*_b)^2]^{1/2}$$

"L*w, a*w, and b*w" represent L*, a*, and b* values measured on a white background, respectively. "L*b, a*b, and b*b" show the L*, a*, and b* values measured on a black background.

Degree of conversion (DC)

The surface treatment procedures (sandblasting, acid-etching, bonding) were performed as mentioned in the shear bond strength test. The polymerized resin samples in 0.2±0.05 mm thickness that were sandwiched between the IRM and dentin were taken, and the DCs of the luting materials were measured from the upper surface of each resin material (composite resin or resin cement) facing the

blocks. In addition, the resin samples to be used as the control group were polymerized by slightly compressing between two glasses. The thickness of each sample was verified after polymerization using a digital vernier caliper (INOX IP54 calipers, Micro Precision Calibration Inc, CA, USA).

Fourier Transform- Infrared Spectrophotometer (FT-IR, PerkinElmer 400 FT-IR/FT-FIR Spectrometer Spotlight 400 Imaging System, PerkinElmer, Waltham, MA, USA) was used for DC measurement of the luting materials. The spectra of the samples placed on the Attenuated Total Reflectance (ATR) cell of the device were measured before and 10 minutes after polymerization.

After each measurement, the ATR platform and measurement tip were cleaned with ethanol. All measurements were carried out in the 450-4000 cm^{-1} wavelength range. After one reference measurement, 20 additional scans were performed for each sample at 4 cm^{-1} resolution. The graphs of the molecular bond structure of the samples were obtained and by using the absorbance values corresponding to the aromatic C = C bonds around 1608 cm^{-1} wavelength and the aliphatic C = C bonds around 1638 cm^{-1} wavelength of polymerized and nonpolymerized samples, the DCs of resin materials were calculated with the following formula (Figure 2);

$$DC\ (\%) = \left(1 - \frac{(1638\ cm^{-1}/1608\ cm^{-1})\ after\ curing}{(1638\ cm^{-1}/1608\ cm^{-1})\ before\ curing}\right) x100$$

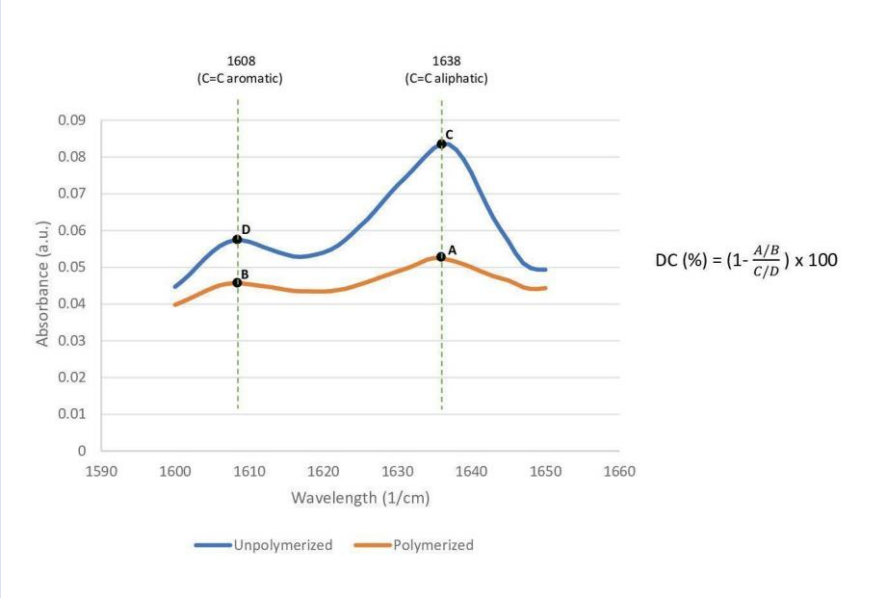

Figure 2: Calculation of the degree of conversion using the peak absorbance values corresponding to the aromatic C=C double bonds around 1608 cm-1 and the aliphatic C=C double bonds around 1638 cm-1 on FT-IR.

Statistical analysis

Statistical analysis of the obtained data was performed using a SPSS 22.0 (IBM Inc, Chicago, IL, USA) program. The Kolmogorov-Smirnov test was used for the analysis of the normality of the data distribution. Three-way analysis of variance (ANOVA) was used to analyze the effect of indirect restorative material type, indirect restorative material thickness, the type of luting materials on shear bond strength and DC. The Chi-Square test for the analysis of fracture types and Tukey Post-hoc test to detect significant differences between the groups were used. The significance level for all comparisons was determined as ($p<0.05$).

Results

Shear Bond Strength Test

The means of shear bond strength values, standard deviations and statistical differences according to the luting materials, the IRMs and thickness factor are given in Tables 2 and 3.

Three-way ANOVA analysis showed that the luting material had an effect on the bond strength. In pair-wise comparisons, it was found that Rely X U200 resin cement showed significantly lower bond strength than Z250 and X-tra fil ($p<0.05$). However, there was no statistically significant difference between the Z250 and X-tra fil groups ($p>0.05$).

When Lava Ultimate and IPS e.max restorative materials were compared, no statistical difference was observed between the two IRMs in terms of shear bond strength to dentin ($p=0.546$). In addition, no statistically significant difference was observed between the thickness of 2 mm and 4 mm ($p=0.322$).

Table 2. The means of SBS values (MPa), standard deviations (SD) of the groups, and statistical differences between the groups according to luting materials, restorative materials, and the thicknesses of the materials

	Subgroups	N	Mean (MPa)	SD	P Values
Luting Materials	Z250	48	7.1^{A}	2.1	0.000
	X-tra fil	48	5.6^{A}	1.9	
	RelyX U200	48	2.3^{B}	0.9	
Restorative Materials	Lava	72	4.7	2.5	0.546
	e.max	72	5.3	2.7	
Thickness	2 mm	72	4.5	2.5	0.322
	4 mm	72	5.5	2.7	

The different uppercase letters indicate statistical differences between the groups.

Table 3. The means of SBS values (MPa), standard deviations (SD) of the groups, and statistical differences between the groups.

Restorative Materials	Thickness	N	Luting Materials	Mean SBS	SD
e.max	**2 mm**	12	Z250	6.9^{de}	2.3
		12	X-tra fil	5.9^{cd}	1.7
		12	RelyX U200	2.3^{ab}	0.7
	4 mm	12	Z250	8.1^{e}	2.3
		12	X-tra fil	5.6^{cd}	1.9
		12	RelyX U200	3.1^{ab}	0.6
Lava	**2 mm**	12	Z250	6.4^{de}	1.3
		12	X-tra fil	4.1^{bc}	0.9
		12	RelyX U200	1.6^{a}	0.5
	4 mm	12	Z250	7.3^{de}	1.6
		12	X-tra fil	6.6^{de}	1.9
		12	RelyX U200	2.3^{ab}	0.8

The different superscripts letters indicate statistical differences between the groups.

Analysis of the Fracture Types

The fracture types and distribution of the groups are shown in Table 4. SEM images of the fractured surfaces of the groups are given in Figure 3. While a total of 12 (25%) pre-test failures were observed in the RelyX U200 group in this study, no pre-test failure was observed in the X-tra fil and Z250 groups. In the examinations under the stereomicroscope, adhesive type fracture (76.4% between resin-dentin and 6.2% between resin-IRM) was observed in 82.6% of the samples, and followed by cohesive (14.6%) and mixed (%2.8) fracture type, respectively. It was observed that all of the cohesive type fractures were in the body of luting material. When the luting materials were compared, while no statistical difference was observed between Z250 and X-tra fil in terms of the number of adhesive, cohesive and mixed failure ($p>0.05$). It was found that RelyX U200 resin cement had greater number of adhesive failure, fewer number of cohesive and mixed failure than the other two groups ($p<0.05$).

Table 4. The distribution of failure modes of the groups.

Luting Materials	*Subgroups*	*Adhesive (%)*		*Cohesive (%)*			*Mixed (%)*	*Pre-test failure*
		Between dentin-LM	**Between IRM-LM**	**Within dentin**	**Within LM**	**Within IRM**		
Z250	e.max 2 mm	9 (%75)	3 (%25)	-	-	-	-	-
	e.max 4 mm	10 (%83)	-	-	-	-	2 (%17)	-
	Lava 2 mm	8 (%67)	-	-	1 (%8)	-	3 (%25)	-
	Lava 4 mm	8 (%67)	-	-	1 (%8)	-	3 (%25)	-
X-tra fil	e.max 2 mm	7 (%58)	-	-	2 (%17)	-	3 (%25)	-
	e.max 4 mm	9 (%75)	3 (%25)	-	-	-	-	-
	Lava 2 mm	9 (%75)	-	-	-	-	3 (%25)	-
	Lava 4 mm	10 (%83)	-	-	-	-	2 (%17)	-
RelyX U200	e.max 2 mm	10 (%83)	2 (%17)	-	-	-	-	-
	e.max 4 mm	10 (%83)	-	-	-	-	2 (%17)	-
	Lava 2 mm	11 (%92)	1 (%8)	-	-	-	-	5
	Lava 4 mm	9 (%75)	-	-	-	-	3 (%25)	7

IRM; indirect restorative material, LM; luting material

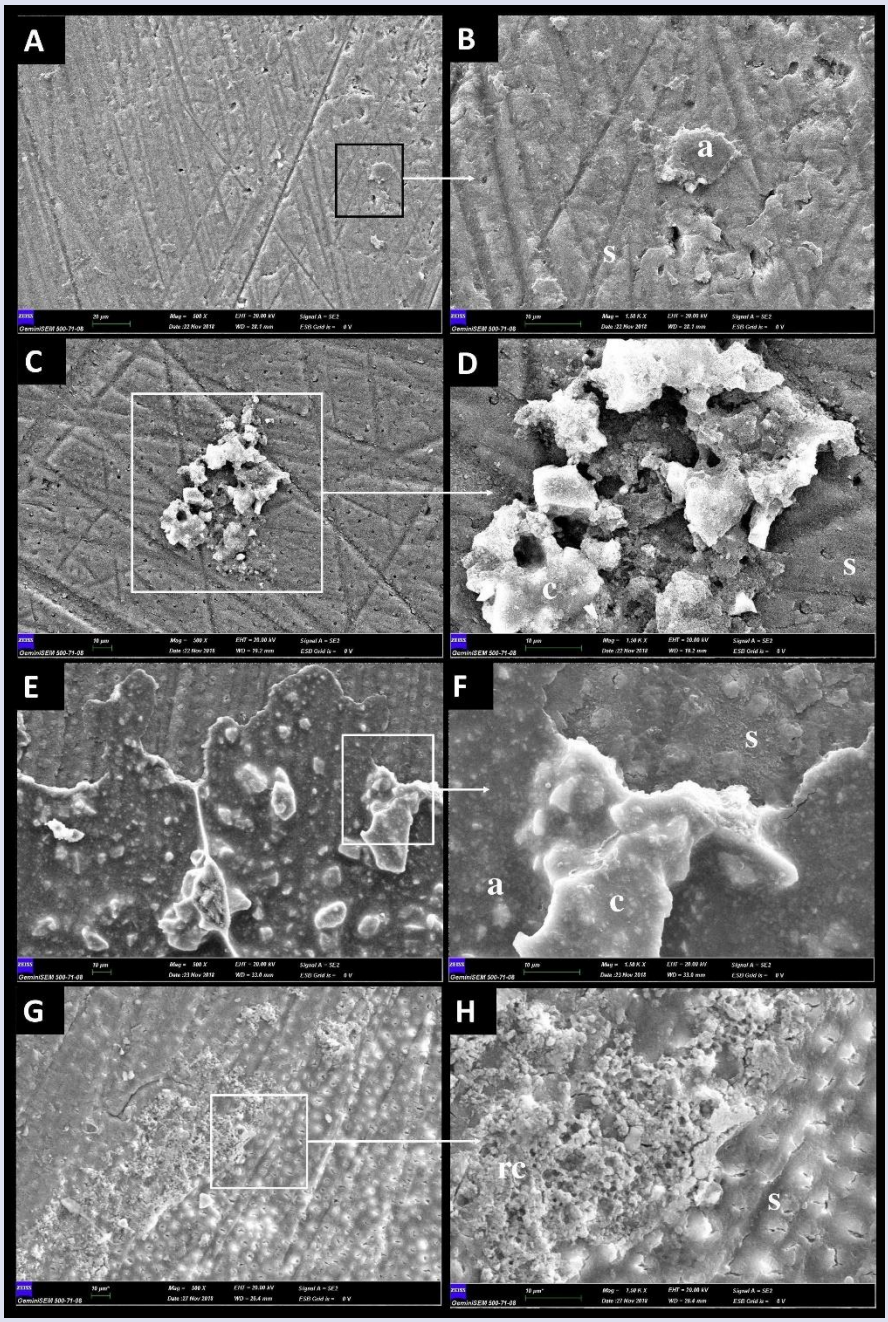

Figure 3: A, B; SEM image of an "adhesive" type failure of X-tra fil-2 mm-Lava group at 500x (A) and 1500x (B) magnification. C, D; SEM image of an "mixed" type failure of X-tra fil-4 mm-Lava Ultimate group at 500x (C) and 1500x (D) magnification. E, F; SEM image of an "mixed" type failure of X-tra fil-2 mm-IPS e.max group at 500x (E) and 1500x (F) magnification. G, H; SEM image of an "mixed" type failure of RelyX U200-4 mm-Lava Ultimate group at 500x (G) and 1500x (H) magnification. (s: smear layer, a: adhesive remnant, c: composite resin, rc: resin cement)

Translucency assessment of the blocks in different thicknesses (2 mm and 4 mm)

The L*, a*, b* and TP values obtained after the measurements of the blocks on white and black background are given in Table 5. Lava Ultimate showed the highest translucency value of 2 mm (11.1), followed by IPS e.max of 2 mm (9.5). Lava Ultimate 4 mm (2.8) and IPS e.max 4 mm (2.4) showed lower translucency values.

Table 5. L, a and b values of the Lava Ultimate and IPS e.max blocks over the white and black backgrounds, the correspondent translucency parameters (TP)

			Optical properties			
Materials	**Thickness**	**Background**	**L***	**a***	**b***	**TP**
Lava	2 mm	White	85.3	0.2	22.4	11.1
		Black	77.2	-1.5	15	
	4 mm	White	79.1	-0.5	17.9	2.8
		Black	77.2	-1.4	16	
e.max	2 mm	White	84.5	0.7	23.5	9.5
		Black	78.3	-1.2	16.5	
	4 mm	White	79.1	0.3	20.3	2.4
		Black	78.3	-0.7	18.3	

Degree of conversion (DC)

The means of the DCs, standard deviations and statistical differences of the groups are given in Tables 6 and 7. When the FT-IR analysis results were evaluated statistically, a significant difference was found between the DCs of the luting materials ($p<0.05$). X-tra fil showed significantly higher DC than Z250 ($p<0.05$). No statistically significant difference was observed between Z250 and RelyX U200 in terms of monomer conversion ($p>0.05$). When the restorative materials were compared among themselves, the mean DC of the luting materials in the Lava Ultimate groups was found to be similar to IPS e.max ($p>0.05$). When DC of restorative materials were compared according to thickness parameter, only Lava Ultimate 4 mm specimens were found to show significantly lower DC than other groups ($p<0.05$), while no statistically significant difference was observed between the other groups ($p>0.05$).

Table 6. The means of degree of conversions (DC), standard deviations (SD) of the groups, and statistical differences between the groups (D) according to luting materials, restorative materials, and the thicknesses of the materials.

	Subgroups	**N**	**DC (%)**	**SD**	**D**
Luting materials	Z250	20	46.8	2.6	b
	X-tra fil	20	52.9	3.3	a
	RelyX U200	20	51.6	3.9	a, b
Restorative materials	e.max	30	51.8	3.1	X
	Lava	30	49.1	3.4	X
Thickness	e.max 2 mm	15	52.9	2.7	A
	e.max 4 mm	15	50.7	2.4	A
	Lava 2 mm	15	53.9	2.9	A
	Lava 4 mm	15	44.2	2.3	B

Different letters show the differences within the groups according to luting materials, restorative materials and thicknesses of the materials.

Table 7. The means of degree of conversions (DC), and standard deviations (SD) of the groups.

Luting Materials	**Subgroups**	**N**	**DC (%)**	**SD**
Z250	Control	5	54.3	3.2
	e.max 2 mm	5	48.7	3.4
	e.max 4 mm	5	48.1	3.1
	Lava 2 mm	5	50.3	2.9
	Lava 4 mm	5	40.1	2.1
X-tra fil	Control	5	64.8	4.3
	e.max 2 mm	5	55.9	3.9
	e.max 4 mm	5	51.3	3.7
	Lava 2 mm	5	54.9	3.4
	Lava 4 mm	5	49.3	3.6
RelyX U200	Control	5	59.4	4.3
	e.max 2 mm	5	54.1	3.3
	e.max 4 mm	5	52.7	2.9
	Lava 2 mm	5	56.4	2.6
	Lava 4 mm	5	43.3	2.5

Discussion

Today, IRMs are frequently used in the restoration of teeth with extensive hard tissue loss due to caries. There are different types of these materials such as all-ceramic, resin-added ceramic or ceramic-added resin (hybrid).[1,2,5] When the different chemical compositions of the materials produced by different manufacturers are taken into account, it is not possible to say that all the restorative materials used have the same optical properties such as light transmission, absorption, scattering and reflection. The polymerization of light or

dual-curing resin materials used for luting of these materials and their adhesion properties, mechanical strength may be indirectly affected by these optical properties.[10,14,15] It should be also kept in mind that the vertical thickness of the prepared restoration is not uniform in all regions of the cavity. Especially gingival step regions of restorations and some restorations like endocrowns present deeper vertical thickness that can prevent the light transmission.

Recently, the researchers have looked for alternative luting materials to resin cements due to their disadvantages such as discoloration, low mechanical properties due to insufficient filler content, low adhesion ability, and inability to ideally fill the gaps in the restoration-tooth interface.[16,17] However, in the literature, there are very few studies testing alternative luting materials.[6,7] Composite resins which have higher filler content compared to resin cements, can be an alternative luting material due to their superior mechanical properties, long-term esthetic stability, and most importantly, their ability to fill the micro and macro gaps between the indirect restoration and the tooth tissue.[6] For this reason, the effect of the material and thickness factors on the DC (polymerization potential) and adhesion of three different resin materials (a bulk-fill, a conventional resin composite and a resin cement) was compared in the present study. In our study, RelyX U200, a self-adhesive resin cement, showed lower shear bond strength than Z250 and X-tra fil. In consistent with the results of our study, in two studies conducted by Kameyama et al.[6] (comparing a conventional resin composite with a resin cement (Variolink II, Ivoclar)) and Urcuyo Alvarado et al.[7] (comparing a preheated resin composite with RelyX U200), traditional resin composites were found to be more successful. The manufacturer claims that RelyX U200 resin cement which is a self-adhesive resin cement does not require additional etching and adhesive application steps. However, in the present study, low bond strength of RelyX U200 may have resulted from the inability of this material to sufficiently penetrate the collagen network and tubules and the hydroxyapatite complex structure in dentin.[18] Moreover, Yin et al.[18] reported that the use of a universal adhesive to dentin prior to the application of RelyX U200 increased the bond strength of resin to dentin. So, the lack of additional chemical bonding provided by functional monomers such as Vitrebond copolymer and 10-MDP of the adhesive resin used in the present study could be another reason of low bond strength of RelyX U200.[19,20] In addition, self-adhesive resin cements have higher water absorption and dissolution properties than paste-like resin composites due to their more hydrophilic structure originating from the acidic monomers that they contain,[16] and therefore RelyX U200 groups may be affected extensively by thermal cycle procedure in this study.

In the present study, it was observed that the effect of Lava Ultimate and IPS e.max on the bond strength of the luting materials to dentin was similar as mentioned in a study by Frankenberger et al.,[8] which found similar effects of both Lava Ultimate and IPS e.max CAD materials on bond strength. In another study that Lava Ultimate and IPS e.max were used, higher bond strength was observed in Lava Ultimate groups, and the researchers argued that Lava Ultimate offers higher bond strength due to the chemical similarity of the resin in its content with the luting cement.[21] However, in our study, the high bond strength between the resin and the IRM was not important, since most of the failure types during the test occurred between the resin and dentin.

The thickness of the IRMs may adversely affect the polymerization of the resin by changing the optical properties of the light passing through the material, affecting the power, wavelength and intensity of the light reaching the underlying resin. Consequently, compromising of polymerization may jeopardize the mechanical properties of the resin and the bond strength to dentin.[10-12] However, when the thickness parameter was evaluated in the present study, the effect of 2 and 4 mm thicknesses on the bond strength was found to be similar. This may be due to the fact that both thicknesses allowed light transmission at a level that did not affect the bond strength.

In the present study, in order to test the bond strength of luting materials to dentin, the use of them with an IRM and then breaking off the luted IRMs was preferred instead of applying them directly on the dentin tissue. This method is more similar to clinical use. However, the bond strength values may have been found to be relatively low in general due to the facts that the light has to pass through a IRM before reaching the dentin, the thermal expansion differences of the IRMs and the luting agent due to the thermal changes during the thermal cycle, and the degradation of the luting material due to contact with water from all sides. Especially the high number of pre-test failures observed in RelyX U200 groups after the thermal cycle supports this situation.

Studies have reported that samples with mostly cohesive and mixed failure offer higher bond strength than specimens with adhesive failure.[22,23] In addition, it has been reported that the incidence of pre-test failure is high in cases that the bond strength is low.[24] In the present study, the highest pre-test failure and adhesive failure were observed in the RelyX U200 group. This can be attributed to the low mean bond strength offered by this group. Chrisostomo et al.[24] reported that low bond strength and high pre-test failure were observed if acid and adhesive resin were not used before RelyX U200 and another self-adhesive resin cement (MaxCem Elite, Kerr) on enamel. In addition, in the present study, it was found that the majority of the adhesive failures (76.4%) occurred at the resin-dentin interface. This situation may show that the luting materials bonded to the blocks better than they did to the dentin. These results are consistent with the findings of the study conducted by Wahsh et al.[21]

In studies evaluating the bond strength of resin to dental tissues, thermal cycle and water storage are generally used for the aim of aging of the samples.[25,26] In the present study, 5000 thermal cycles was preferred,

which corresponds to approximately 6 months of aging.[27] In fact, since the bond surface area of the prepared samples is large (9mm^2), it would be expected to observe more cohesive or mixed failure types. However, we think that the bonding weakened significantly due to the simultaneous water absorption, dissolution and bonding interface degradation with the thermal aging effecting of the adhesive resin from all sides, due to the absence of dentinal walls or a cavity preparation. In addition, the bond strength could be negatively affected by the mismatches in the coefficient of thermal expansion of the luting material, dentin and IRM.[28]

The DC of resin materials determines the polymerization quality,[29] so it is a parameter that affects the physico-chemical and mechanical strength of the material. If the IRMs do not allow light to reach underlying resin, the resin's monomer conversion is adversely affected.[10] This reduces the bond strength of resin to dentin and IRM, as well as its mechanical strength.[10-12] In the present study, the DC of the adhesive resins, the translucency properties of IRMs and the correlation between the two parameters were also evaluated to support the bond strength test.

Previous studies have reported that bulkfill resin composites have higher monomer conversion degrees than conventional resin composites.[30,31] Similarly, in the present study, X-tra fil, a bulk-fill resin composite, showed higher monomer conversion compared to RelyX U200 and Z250. The manufacturer of X-tra fil resin composite, decreased the specific surface between fillers and the organic matrix increasing the filler size, consequently reduced the light scattering.[32] X-tra fil has high translucency despite its high filler loading, which is related to the increased filler size and by the improved refractive indices of the filler particles and the resin matrix.[30,33] However, X-tra fil showing high DC did not offer high bond strength. It was observed that there was no direct correlation between DC and bond strength of RelyX U200 resin cement, which showed lower DC than X-tra fil but similar to Z250. This suggests that the other factors such as depth of penetration, mechanical strength, water absorption and dissolution are also effective on bond strength.

In the present study, the mean DCs of the luting materials in Lava Ultimate 2 mm and IPS e.max 2 mm groups were found close to each other. However, the mean DC of Lava Ultimate samples in the 4 mm groups was lower than that of IPS e.max. On the other hand, TP values of IPS e.max and Lava Ultimate were found close to each other in both 2 mm and 4 mm groups. Different factors such as ceramic, glass and resin ingredients in the chemical content of the materials, filler particle size and shape can also affect optical parameters such as light transmission, absorption and scattering.[14] Therefore, there may not be a direct correlation between DC and TP. Similar to the findings of our study, Jesus et al.[14] stated that there was no direct relationship between DC and TP in a study that they conducted with IPS e.max blocks with different translucency values.

It can be predicted that increasing in the thickness of the IRM will allow less light transition and consequently affect the polymerization of the luting material.[15] When the effect of the thickness parameter on the degree of conversion was evaluated in the present study, it was found that the 4 mm thick Lava Ultimate blocks caused lower DC of the luting material compared to the other groups. Ilie et al.[15] reported that one of the factors determining the polymerization quality of the resin material was the surface hardness, and they investigated the effect of thickness on TP and surface hardness. The researchers reported that TP and hardness decreased with the increase in thickness. Although similar results were not found in present study, the fact that any further increase in thickness (> 4mm) of IRMs could compromise the polymerization of resin should not be ignored.

The present study is an in-vitro study performed by ignoring the factors such as humidity, changes both in temperature and pH in oral environment, patient habits, the effects of muscles functioning during chewing and swallowing, the effect of saliva, pulpal temperature and pressure, malocclusions. Therefore, additional in-vivo and in-vitro studies are needed to support the study results.

Conclusions

Within the limitations of this study, the following conclusions can be drawn;

1. Conventional resin composites and bulk-fill resin composites can be alternative luting materials to resin cements.
2. Thickness increase of IRMs did not change BS, while decreased the TP, and the DC only for Lava Ultimate.
3. IPS e.max did not affect DC and BS up to 4 mm, but TP decreased by thickness increase.
4. Lava Ultimate did not affect BS up to 4 mm, but DC and TP decreased by thickness increase.

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Conflict of interest

The authors declare no competing interests.

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