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Degree of Conversion and Bond Strength of Resin Cements through Different Thicknesses of Lithium Disilicate Ceramic using Different Curing Modes

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Abstract

Objectives: The aim of this in vitro study was to assess the physical and mechanical properties of resin cements to ceramic substrate using different curing modes by evaluating the degree of conversion and bond strength of these cements.

Methods: Hundred twenty square lithium disilicate ceramic discs specimens of three thicknesses (0.5, 1 and 1.5 mm) and 10 x 10 mm diameter were bonded to 120 bovine teeth using two resin cements (one light cure and one dual cure) and using two curing modes (ramp and continuous). As a result, 12 experimental groups were established for bond strength testing. Degree of conversion of luting cements was evaluated using Fourier transform infrared spectroscopy (FTIR).

Results: Using the continuous mode compared to the ramp after controlling the type of resin and material thickness showed no significant difference ($P > 0.001$) in SBS and DC. The effect of changing the material thickness between 0.5 mm, 1 mm and 1.5 mm after controlling the resin type and mode of light curing, showed significant difference ($P < 0.001$) from 1 mm to 1.5 mm using light-cured resin and continuous curing mode for SBS. While for the DC these correlations between different material thicknesses and both light cure type of resin and continuous light-curing mode was significant ($P < 0.001$), it was also significant with dual cure cement. This study also evaluated the effect of using dual-cured resin cement compared to the light-cured resin cement on the SBS and DC, for the SBS the effect was significant with higher thicknesses ($P < 0.001$ for the thickness of 1.5 mm) but not significant with thicknesses less than this such as 0.5 mm and 1 mm ($P > 0.05$).

Conclusion: There is no change on the effect of changing light curing mode on the DC and SBS increasing the thickness decrease SBS and DC, dual-cured resin performed better when used for thickness of 1.5 mm.

Keywords: Resin cements, lithium disilicate, curing modes

Introduction

All-ceramic restorations have become very popular due to their excellent esthetics, high color stability, wear resistance, and biocompatibility. In modern dental practice, conservative ceramic restorations for changing the position, shape, or color of anterior teeth are widely used. The esthetic quality of the material is not the only criterion to consider for the success of ceramic veneers.[1-3] Resin cements were used to fix ceramic veneers to the tooth structure. Because of its mechanical properties superior to conventional cement (resin-free), and its ability to adhere to the restorative material and the tooth structure with or without an adhesive system.[4] These cements have different monomers that are joined together during the polymerization reaction.[4-10] commercially available resin cement for luting ceramic veneers can be light-activated or dual-cured depending on the opacity and thickness of restoration. light-activated resin cement is recommended when curing unit's light can pass through the restoration. These cements are available as a single paste containing a photoinitiator system consisting of a photosensitive component (typically camphorquinone) and a tertiary amine.[11,12] The presence of light with a wavelength of 480 nm (blue region of the visible spectrum) activates camphorquinone, which binds to the tertiary amine and then releases two free radicals, which initiates the conversion of the monomers.[13] Chemically cured systems are recommended to be used under opaque or thick restorations, due to the blockage of light. Whereas Photo-cured cements are mainly indicated for translucent veneers, due to the possibility of light transmission through the restoration. Dual-cured are more versatile systems and, theoretically, can be used in either situation, since the presence of both curing mechanisms might guarantee a high degree of conversion. The degree of conversion is crucial in determining the mechanical performance of resin-based materials and their biocompatibility.[14-18] (Low DC) of the cement may result in degradation of resin-based cements which intern reduces the bond strength at the restoration margin, which may mean the clinical loss of the restoration either by debonding, fracture or secondary caries.[19-22]

Material and Methods

For this study, two resin cements were evaluated, one resin cement is dual-cured resin (Variolink Esthetic DC, shade warm, Ivoclar Vivadent; Schaan, Liechtenstein), the other cement is light cured (Variolink Esthetic LC, shade warm, Ivoclar Vivadent; Schaan, Liechtenstein). The materials specifications used in this study are shown in Table 1.

One-hundred twenty ceramic veneers (Lithium Disilicate glass-ceramic IPS e.max CAD LT (Low translucency, A1/C14), Ivoclar Vivadent; Schaan, Liechtenstein) of three thicknesses (0.5, 1, and 1.5) mm of one diameter (10 × 10 mm). The cutting device (Struers-minitom, Copenhagen, Denmark), was used to obtain square-shaped specimens by cutting the pre-sintered stage of IPS e-max CAD blocks to specific thickness using low-speed diamond Cut-off Wheel (MOD 13>HV 800,

Table 1. **Materials used for the study**

Product name	Material	Manufacture	Shade	Batch no.
IPS e.max CAD LT/C14	Lithium Disilicate	Ivoclar vivadent, Schaan, Liechtenstein	A1	B601187
Variolink Esthetic DC	Dual-cured Resin cement	Ivoclar vivadent, Schaan, Liechtenstein	Warm	W95470
Variolink Esthetic LC	Self-cured resin cement	Ivoclar vivadent, Schaan, Liechtenstein	Warm	X09663
Total etch	37% phosphoric acid	Ivoclar vivadent, Schaan, Liechtenstein		W31957
IPS Ceramic Etching Gel	5% Hydrofluoric acid	Ivoclar vivadent, Schaan, Liechtenstein		R48184
Monobond Plus	Silane coupling agent	Ivoclar vivadent, Schaan, Liechtenstein		X56714
Adhesive Universal	Adhesive Resin	Ivoclar vivadent, Schaan, Liechtenstein		W97834

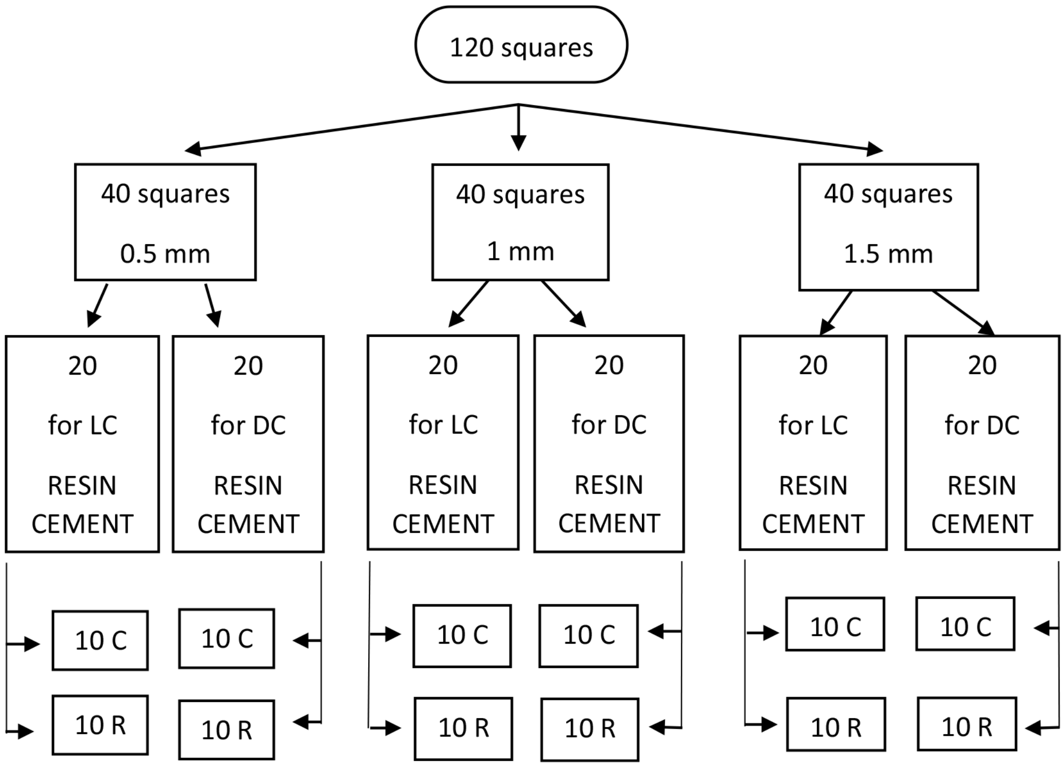

Fig. 1 **Diagram showing flow chart of the study groups for shear bond strength test; LC (light cure); DC (dual cure); R (ramp curing mode); C (continuous curing mode).**

size 127 mm dia. × 0.4mm × 12.7 mm dia. Struers A/S Denmark) underwater. Then the squares were cleaned in both sided with air/water for 15s and let to dry. Then all squares were fired according to the crystallization program recommended by Ivoclar Vivadent.

Bond Strength Measurement

For the bond strength study 120 freshly extracted bovine central incisor teeth were used. All the teeth were kept in 0.1% Thymol solution at room temperature until tested. The labial enamel of teeth was removed superficially; avoiding dentinal exposure. All teeth were treated with 37% phosphoric acid (Total etch, Ivoclar Vivadent; Schaan, Liechtenstein) for 15 seconds, then washed and dried with air. Adhesive bonding resin (Ivoclar Vivadent; Schaan, Liechtenstein) was applied for 5 seconds using disposable micro brush tips (Vivadent applicator Brush, Ivoclar Vivadent; Schaan, Liechtenstein) and light cured for 20 seconds. All ceramic samples, regardless of thickness, were surface treated with 5% hydrofluoric acid for 2 minutes (IPS Ceramic Etching Gel, Ivoclar Vivadent; Schaan, Liechtenstein). The acid was removed with an air/water spray for 5 minutes with water. Following drying of the specimens, a layer of silane coupling agent (Monobond Plus, Ivoclar Vivadent; Schaan, Liechtenstein) was applied and allowed to react for 1 minute. An appropriate amount of resin cement was extruded from the tip of the cement syringe and applied to the enamel surface of bovine teeth and ceramic cube, the ceramic discs were pressed onto the tooth surface for 20s, and the samples were cured with light cure (LED) for 40s with direct contact after removing the excess cement with a disposable brush. All specimens were stored at 37ºC in relative humidity and darkness for 48 hours before shear bond testing with a universal testing machine (WP300; Zwick, Gunt, Hamburg, Germany). Each sample was mounted in a holding device within a universal testing machine. The samples were loaded at a speed of 1 mm/min with the crosshead chisel toward the enamel-cement ceramic complex. The SBS (MPa) was calculated by dividing the load Newtons (N) by the surface area of the enamel-ceramic bonding (mm^2) [Fig 1].

Degree of Conversion

For testing the degree of conversion (DC) only three samples, one of each thickness, approximately one gram of non-cured cement was putted between two plastic films and pressed in a pneumatic press at 10 kgN until thin films is achieved. Then light-cured (mini-LED Acteon, France) through different thickness of ceramic, putted over the film so the light pass through for 40 seconds with a 1000 mW/cm^2 irradiance. The degree of conversion of the resin cements was evaluated using Fourier transform infrared spectroscopy (FTIR) (Nicolet iS50; Thermo Fisher, Waltham, Massachusetts, united states).

60 ceramic samples were divided into 12 groups (n = 5) and both cements polymerized through these squares, with conversion measured using FTIR. The degree of conversion was calculated using the absorption peak of the c=o ester group as a reference using this formula:

$$\% \text{ DC} = 100 \left[1 - (\text{R cured}/\text{R non-cured})\right]$$

Results

Shear Bond Strength

Using the continuous mode compared to the ramp curing mode shows no significant differences in SBS on as shown in Table 2, after controlling the material thickness and type of resin cements regardless of the curing mode.

Table 3 shows the effect of the type of resin cement (light-cure vs dual-cure) on SBS, the results showed that after controlling the effects of other variables no significant differences in SBS using 0.5- and 1.0-mm thickness of ceramic samples using both type of cements at P = 0.05. While using a ceramic sample of 1.5 mm showed statistically significant SBS differences using light cure or dual cure resin cements (P = <0.001 and <0.001 respectively).

The effect of changing material thickness on SBS (0.5, 1 and 1.5 mm) are shown in Table 4. After controlling other variables (resin cement type and curing mode) shows no significant differences in SBS using ceramic thickness of 0.5- and 1.0-mm. While comparing 0.5 mm ceramic sample Vs 1.5 mm samples resulted in statistically different SBS for light cure cement with ramp or continuous curing mode (P = 0.026 and 0.002 respectively). Also comparing 1 mm ceramic sample Vs 1.5 mm samples showed statistically different SBS for light cure cement with ramp or continuous curing mode (P = 0.003 and <0.001 respectively). When the SBS obtained using dual cure cement showed no statistical differences for the 1.5 mm ceramics as compared to both 0.5 and 1.0 mm (Table 4).

Degree of Conversion

The effect of light curing mode of (ramp vs continuous light-curing) results on degree of conversion of the resin cements shown in Table 5, the results showed that after controlling the effects of other variables namely thickness of ceramic samples and type of resin cements there were no significant differences in SBS regardless of the curing mode. Except when the thickness of the ceramic samples was 0.5 mm and the cement was light curing type in this group there was significant differences in SBS where the degree of conversion was 70.37% (5.17) for ramp curing mode as compared to 76.66% (6.08) for continuous curing mode (P = 0.08).

The effect of changing the type of resin cement (light-cure vs dual-cure) on the degree of conversion shown in Table 6, showed that after controlling the effects of other variables namely thickness of ceramic samples and curing mode there were no significant differences on the degree of conversion using 0.5-mm thickness of ceramic samples using both mode of curing. The same results were observed using 1.5 mm ceramic thickness sample cured with continuous mode. While using a ceramic sample of 1.0 and 1.5 mm showed statistically significant differences on conversion rate using ramp curing mode (P = 0.004 and 0.006. respectively).

Table 2. **The effect of changing mode of light curing between ramp and continuous on bond strength measurements (MPa) after controlling for (stratifying) material thickness and type of resin used**

	Mode of light curing				
	Ramp light curing (n = 10)	Continuous light curing (n = 10)	P	Difference in mean	Cohens d
MT = 0.5 (mm) & LC			0.86		
Mean	19.22	19.58		0.36	0.06
MT = 0.5 (mm) & DC			0.79		
Mean	21.93	22.49		0.56	0.14
MT = 1 (mm) & LC			0.78		
Mean f	20.75	21.34		0.59	0.12
MT = 1 (mm) & DC		0.28			
Mean	23.03	23.55		0.52	0.15
MT = 1.5 (mm) & LC			0.49		
Mean	14.56	13.13		–1.43	–0.36
MT = 1.5 (mm) & DC			0.58		
Mean	23.26	24.4		1.14	0.22

MT (material thickness), LC (light curing mode), DC (dual curing mode).

Table 3. **The effect of changing type of resin used between light cure and dual cure on bond strength measurements (MPa) after controlling for (stratifying) material thickness and mode of curing**

	Type of resin material				
	Light Cure ($n = 10$)	Dual Cure ($n = 10$)	P	Difference in mean	Cohens d
MT = 0.5 (mm) & ramp curing mode			0.19		
Mean	19.22	21.93		2.71	0.54
MT = 0.5 (mm) & Cont. curing mode			0.16		
Mean	19.58	22.49		2.91	0.61
MT = 1 (mm) & ramp curing mode			0.27		
Mean	20.75	23.03		2.28	0.61
MT = 1 (mm) & Cont. curing mode			0.28		
Mean	21.34	23.55		2.21	0.46
MT = 1.5 (mm) & ramp curing mode			<0.001		
Mean	14.56	23.26		8.7	2.3
MT = 0.5 (mm) & Cont. curing mode			<0.001		
Mean	13.13	24.4		11.27	2.17

Cont. (continuous curing mode).

Table 4. **The effect of changing material thickness between 0.5 mm, 1 mm and 1.5 mm on bond strength measurements (MPa) after controlling for (stratifying) type of resin used and mode of light curing**

	Material thickness (mm)			1 mm thickness compared to 0.5 mm			1.5 mm thickness compared to 0.5 mm			1.5 mm thickness compared to 1 mm		
	0.5 mm thick ($n = 10$)	1 mm thick ($n = 10$)	1.5 mm thick ($n = 10$)	P	Difference in mean	Cohens d	P	Difference in mean	Cohens d	P	Difference in mean	Cohens d
LC & ramp				0.46			0.026			0.003		
Mean	19.22	20.75	14.56		1.53	0.28		−4.66	−0.86		−6.19	−1.52
LC & Cont.				0.39			0.002			<0.001		
Mean	19.58	21.34	13.13		1.76	0.33		−6.45	−1.48		−8.21	−1.64
DC & ramp				0.6			0.52			0.91		
Mean	21.93	23.03	23.26		1.1	0.36		1.33	0.41		0.23	0.07
DC & Cont.				0.6			0.35			0.68		
Mean	22.49	23.55	24.4		1.06	0.26		1.91	0.34		0.85	0.17

The effect of ceramic material thickness (namely 0.5, 1 and 1.5 mm) on degree of conversion are shown in Table 7. The results showed that after controlling the effects of other variables namely resin cement type and curing mode there were significant differences on the degree of conversion using ceramic thickness of 0.5- and 1.0-mm except for the group which used light cure resin cement cured in ramp mode (P = 038). While comparing 0.5 mm ceramic sample Vs 1.5 mm samples showed statistically different degree of conversion for both light cure cement and dual cure cement cured with ramp or continuous curing mode. In the same line, comparing 1.0 mm ceramic sample Vs 1.5 mm samples showed statistically different degree of conversion for light cure cement with ramp or continuous curing mode (P = 0.003 and <0.001 respectively). While the degree of conversion for dual cure cement showed no statistical differences for the 1.5 mm ceramics as compared to1.0 mm thickness when the cement was polymerized with ramp ($P = 0.73$) or continuous (0.83) mode (Table 7).

Discussion

SBS and DC tests are often performed together for the best clinical outcomes. The main goal of all restorative materials and procedures is high DC, which leads to a very strong bond strength to dentin.[23,24] As a result, this study evaluated the SBS and DC of dual-cured and light-cured resin cement through different thicknesses of lithium disilicate ceramics in an attempt to evaluate the effect of three variations (mode of light curing, resin type, and ceramic thickness) on the SBS and DC.

Many characteristics of the ceramics such as (type of ceramics, thickness, shade, translucency, the resin cement composition, mode of activation, curing light output power, setting time, and distance) influence resin cement polymerization.[25-28] High-intensity light sources are universally recommended for curing resin composites because they are able to improve the immediate depth of cure and mechanical

Table 5. **The effect of changing mode of light curing between RAMP and continuous on Conversion rate (%) after controlling for (stratifying) material thickness and type of resin used**

	Mode of light curing				
	Ramp light curing (*n* = 5)	**Continuous light curing (*n* = 5)**	***P***	**Difference in mean**	**Cohens *d***
MT = 0.5 (mm) & LC			0.08		
Mean	70.37	76.66		6.29	1.12
MT = 0.5 (mm) & DC			0.67		
Mean	69.13	70.61		1.48	0.28
MT = 1 (mm) & LC			0.22		
Mean	67.3	62.98		-4.32	-0.66
MT = 1 (mm) & DC			0.34		
Mean	56.65	60.04		3.39	0.69
MT = 1.5 (mm) & LC			0.17		
Mean	45.72	50.56		4.84	1.12
MT = 1.5 (mm) & DC			0.3		
Mean	55.65	59.3		3.65	0.59

Table 6. **The effect of changing type of resin used between light cure and dual cure on Conversion rate (%) after controlling for (stratifying) material thickness and mode of light curing**

	Type of resin material				
	Light Cure (*n* = 5)	**Dual Cure (*n* = 5)**	***P***	**Difference in mean**	**Cohens *d***
MT = 0.5 (mm) & ramp curing mode			0.72		
Mean	70.37	69.13		−1.24	−0.28
MT = 0.5 (mm) & Cont. curing mode			0.09		
Mean	76.66	70.61		−6.05	−0.96
MT = 1 (mm) & ramp curing mode			0.004		
Mean	67.3	56.65		−10.65	−1.98
MT = 1 (mm) & Cont. curing mode			0.4		
Mean	62.98	60.04		−2.94	−0.48
MT = 1.5 (mm) & ramp curing mode			0.006		
Mean	45.72	55.65		9.93	1.84
MT = 1.5 (mm) & Cont. curing mode			0.016		
Mean	50.56	59.3		8.74	1.67

properties of luting resins. other studies revealed that ramp-cured specimens had significantly higher mean SBS for both dual- and light-polymerized resins than fast and pulse modes.[29,30] In this study, the effect of changing the mode of curing on bond strength revealed that there is no significant difference between using continuous mode and ramp curing mode, as shown in (Table 2). Furthermore, using continuous mode versus ramp cured mode effect on the DC was not significant (Table 5). When appropriate polymerization times are used, curing lights with an intensity of 300 mW/cm^2 appear to effectively cure most resins.[31] Composites activated by visible light polymerize to a comparable extent when irradiated continuously or sequentially for the same total exposure time.[32]

Previous research has showed the value of dual-curing resin cement in clinical situations where the light from the curing unit is unable to reach all regions of the cavity or preparation, such as the apical region of root canals during adhesive post luting or the deep internal areas of preparations for indirect adhesive restorations.[33-36] Thus, using ceramic veneers thicker than 1.5 mm, light-cured cement should be used with caution.[37] The effect of using dual-cured resin compared to the light-cured resin on SBS was evaluated in this study after controlling the material thickness and mode of light-curing, and the correlation was significant with higher thicknesses (*P*-value <0.001 for the thickness of 1.5 mm) but not significant with thicknesses less than this such as 0.5 and 1 mm (*P* values > 0.05) for each variable as shown in Table 3. Furthermore, for a thickness of 1.5mm, the effect of using dual-cured resin compared to the light-cured resin on the DC was significant, as shown in (Table 6). These findings agree that the thickness and color of the restoration are far more influential than the type of restorative material used. For

Table 7. **The effect of changing material thickness between 0.5 mm, 1 mm and 1.5 mm on the Conversion rate (%) after controlling for (stratifying) type of resin used and mode of light curing**

	Material thickness (mm)			1 mm thickness compared to 0.5 mm			1.5 mm thickness compared to 0.5 mm			1.5 mm thickness compared to 1 mm		
	0.5 mm thick (n=5)	1 mm thick (n=5)	1.5 mm thick (n=5)	*P*	Difference in mean	Cohens *d*	*P*	Difference in mean	Cohens *d*	*P*	Difference in mean	Cohens *d*
LC & ramp				0.38			<0.001			<0.001		
Mean	70.37	67.3	45.72		−3.07	−0.53		−24.65	−6		−21.58	−4.44
LC & Cont.				<0.001			<0.001			<0.001		
Mean	76.66	62.98	50.56		−13.68	−2.14		−26.1	−4.5		−12.42	−2.03
DC & ramp				<0.001			<0.001			0.78		
Mean	69.13	56.65	55.65		−12.48	−3.23		−13.48	−2.39		−1	−0.17
DC & Cont.				0.004			0.002			0.83		
Mean	70.61	60.04	59.3		−10.57	−1.75		−11.31	−1.95		−0.74	−0.14

restorations with a thickness greater than 1 mm, a dual-cure or chemical cure resin cement should be used to ensure the best cement properties.[38-39] The effect of changing material thickness between (0.5 mm, 1 mm, and 1.5 mm) on bond strength measurements (MPa) after controlling the type of resin material used and mode of light-curing was also evaluated in the current study. In the experiment using light-cured resin and continuous curing mode when changing thickness from 1 mm to 1.5 mm (increasing thickness), there is a strong reduction in the mean bond strength by −8.21 MPa (*P*-value < 0.001). Whereas the effect of changing material thickness between 0.5 mm, 1 mm, and 1.5 mm on degree of conversion was studied after controlling for (stratifying) resin type and mode of light-curing, the correlations were between different material thicknesses and both light cure type of resin material and continuous light-curing mode of light *P*-value <0.001), it was also significant with dual cure cement.

Conclusion

Within the limitations of this in vitro study, it is possible to conclude that: using continuous mode instead of ramp mode has no significant effect on DC and SBS, when used in a thickness of 1.5 mm, dual-cured resin outperformed light-cured resin in terms of SBS and DC and Increasing the thickness decreases the SBS and DC.

Conflict of Interest

None.

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