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The Effect of Ceramic Restoration Shade and Thickness on the Polymerization of Light- and Dual-cure Resin Cements

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Clinical Relevance

Resin cements are generally considered as the material of choice in cementation of all-ceramic restorations. The decision between light- and dual-cure resin cement may depend on the properties of the ceramic restoration as well as the location of the tooth. The ceramic thickness has a more intense effect on polymerization than ceramic shade.

SUMMARY

Objectives: Inadequately polymerized resin cements may negatively affect the clinical performance of cemented all-ceramic restorations. The purpose of this *in vitro* study was to evaluate the effect of ceramic thickness and shade on the microhardness of various light-cured (LC) and dual-cured (DC) resin cements. The amount of light transmission through the restoration was also evaluated to correlate the results.

Methods: Three different brands of resin cements (Appeal/Ivoclar; Calibra/Dentsply; Nexus 2/Kerr) were used in LC and DC forms to prepare disk-shaped samples (0.5-mm thickness × 5-mm diameter) (n=15). Study group samples were light-cured for 40 seconds (Flashlite 1401/Discus Dental) through four shades (ETC1, ETC2, ETC3, ETC4) and four thicknesses (1 mm, 2 mm, 3 mm, 4 mm) of all-ceramic ingot discs (IPS Empress Esthetic/Ivoclar). Control samples were directly cured without the presence of ceramic. The light transmission through various shades and thicknesses

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of ceramics was measured using a hand-held radiometer (Demetron, Kerr). Vickers microhardness measurements were performed (Micromet/Buehler) at 24 hours following dark storage in 37°C water. Correlation between ceramic shade, thickness, and light intensity readings (mW/cm^2) with respect to microhardness was statistically evaluated using analysis of variance (*p*=0.05).

Results: Ceramic thickness of 3 mm and/or above significantly decreased the microhardness values in all LC and DC groups ($p<0.0001$). Ceramic shade had a significant effect only on Calibra in both LC and DC groups ($p<0.0001$). Microhardness values of LC groups were significantly lower than DC groups ($p<0.0001$). Control groups had significantly higher hardness values in all cement groups ($p<0.0001$). There was a significant correlation between the amount of light transmitted and hardness (*p*=0.000).

Conclusion: The ceramic thickness has a more intense effect on polymerization compared to the ceramic shade. Overlying ceramic thickness of 3 mm and above was found to adversely affect the polymerization of LC and DC resin cements and therefore a 3-mm thickness was considered the critical threshold.

INTRODUCTION

Resin cements are commonly used in the cementation of all-ceramic restorations due to their high esthetics, low solubility, high bond strength, and superior mechanical properties that help reinforce the ceramic restorations.[1–4] Light-cure (LC) cements are used under thin and translucent restorations where there is adequate light transmission. When the restoration thickness is above 1.5-2 mm or its opacity inhibits light transmission, the use of dual-cure (DC) resin cements is advocated.[5–10] Sufficient light transmission is still vital for DC for the initialization of the polymerization process even if its optimal cure is achieved by an autopolymerized catalyst.[2] In both polymerization types, optimal cure is always critical because inadequately polymerized resin cements are prone to have altered mechanical properties, altered dimensional stability, decreased bonding to tooth structures, resulting microleakage, decreased biocompatibility, discoloration, and postoperative sensitivity.[11–14] The factors that affect resin cement polymerization can be listed as ceramic thickness, ceramic shade, ceramic translucency, resin cement composition, and polymerization type as well as the curing light's output power, curing duration, and distance.[10,12,15–19] Commonly, the decision between a LC and a DC resin cement is based on whether the restoration is an anterior or a posterior restoration. Most dentists report that they routinely use LC cements for all anterior restorations and DC cements for all posterior restorations regardless of the properties of the ceramic restoration. Nevertheless, independent from the location of the restoration, the shade and thickness of the ceramic restoration may vary considerably. Even an esthetic anterior restoration may have areas with more ceramic thickness or with a darker shade compared to a posterior onlay.

This *in vitro* study evaluates the microhardness of LC and DC resin cements polymerized through different shades and thicknesses of the same ceramic material to compare the effect of ceramic's properties on the degree of polymerization. Additionally, light transmission values recorded through various ceramics were correlated with the findings.

MATERIALS AND METHODS

All-ceramic ingot discs (IPS Empress Esthetic, Ivoclar, Schaan, Liechtenstein) were fabricated in ETC1, ETC2, ETC3, and ETC4 shades and in 1 mm, 2 mm, 3 mm and 4 mm thicknesses (11 ± 0.1 mm diameter).

ETC1 ingot shade corresponds with the veneering ceramic shades A1, B1, and C1. In a similar aspect, ETC2 ingot shade corresponds with A3, A3.5, A4, and D3 shade veneering ceramics and gets a brown hue as the thickness increases. ETC3 ingot shade corresponds with B3, B4, and D4 shade veneering ceramics and gets a yellow-brown hue with increasing thickness. ETC4 ingot shade on the other hand, corresponds with C2, C3, and C4 shade veneering ceramics and has a clearly gray hue (Figure 1).

A digital caliper was used to confirm the thickness of each disc. All discs at their proper thicknesses were sanded down for surface smoothness under standardized conditions using 600- and 1200-grit silicon carbide sandpaper (Carbimet, Buehler, Evanston, IL, USA). Surface polishing was performed using 3- and 6-μm diamond polishing paste (Metadi supreme polycrystalline diamond suspension, Buehler) with cloth disc (8/0 Mastertex, Buehler). Ceramic discs were ultrasonically cleaned (VWR Model 150D, Westchester, PA, USA) for 15 minutes to eliminate any oil or dirt contamination.

The light transmission value of each thickness and shade of ceramic was measured by placing the disc

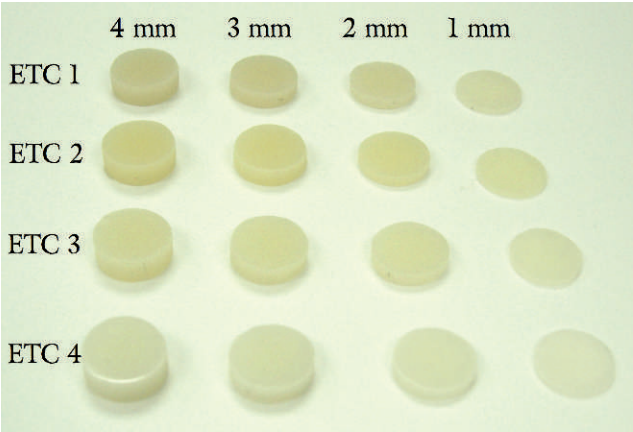

Figure 1. *Various shades and thicknesses of ceramics through which the resin cement samples were cured.*

on the aperture of the hand-held radiometer (Demetron, Kerr, Orange, CA, USA) and recording the average of resultant light readings through the disc in mW/cm^2.

The study included three resin cements from different manufacturers. Resins were in corresponding shades in both LC and DC types (Nexus 2, Kerr; Appeal, Ivoclar Vivadent; Calibra, Dentsply Caulk). Appeal light-cure was later released to the market as Variolink Veneer. Appeal dual-cure was removed from the market soon after this study was completed. The resin cements are listed in Table 1.

Each of the six resin cement groups included 17 subgroups (4 ceramic shades $\times$ 4 ceramic thicknesses + 1 control group polymerized without ceramic). A total of 510 resin cement samples were fabricated (n=5).

In total, 510 standard cylindrical ring stainless steel molds were used with dimensions 5 mm inner diameter $\times$ 0.5 mm depth $\times$ 11 mm outer diameter. These molds served as individual single-use molds that facilitated fabrication, storage, and testing of the resin cement samples (5 mm diameter $\times$ 0.5 mm depth). A separate positioning ring was used to stabilize the ceramic disk and prevent displacement of the sample mold during preparation. The positioning ring had inner dimensions that matched the outer dimensions of the actual sample mold and the ceramic disc. Its depth provided stabilization of the resin cement sample and the ceramic disc. Sample preparation is shown in Figure 2.

Resin cements were either directly applied from the syringe (LC) or mixed in a separate mixing pad and applied into the sample mold using a plastic instrument (DC) according to the manufacturer's instructions. Mylar strips, cut in the shape of the sample molds, were used on the bottom of the sample to ensure an even and smooth surface and were also used on the top of the cement to provide isolation from the ceramic disc. Samples were polymerized through the ceramic discs for 40 seconds with an LED curing light held in direct contact with the ceramic disc (Flashlite 1401, Discus Dental, Culver City, CA, USA). Curing light output was continuously monitored and the maximum output of the LED unit was measured as 800 mW/cm^2. Control samples from each cement group were directly polymerized under a Mylar strip without the presence of ceramic.

Table 1: *Resin Cements Used in the Study*

Resin Cement	Manufacturer	Monomer	Resin Shade	Batch Number
Nexus 2 LC	Kerr, Orange, CA, USA	Bis-GMA and dimethacrylate	White	424150
Nexus 2 DC	Kerr, Orange, CA, USA	Bis-GMA and dimethacrylate	White	422017
Appeal LC	Ivoclar Vivadent, Schaan, Liechtenstein	Urethane dimethacrylate and decandiol dimethacrylate	High value +1	F37719
Appeal DC	Ivoclar Vivadent, Schaan, Liechtenstein	Urethane dimethacrylate and decandiol dimethacrylate	High value +1	G23861
Calibra LC	Dentsply Caulk, Milford, DE, USA	Dimethacrylate resins	Light shade	0502071
Calibra DC	Dentsply Caulk, Milford, DE, USA	Dimethacrylate resins	Light shade	0503091

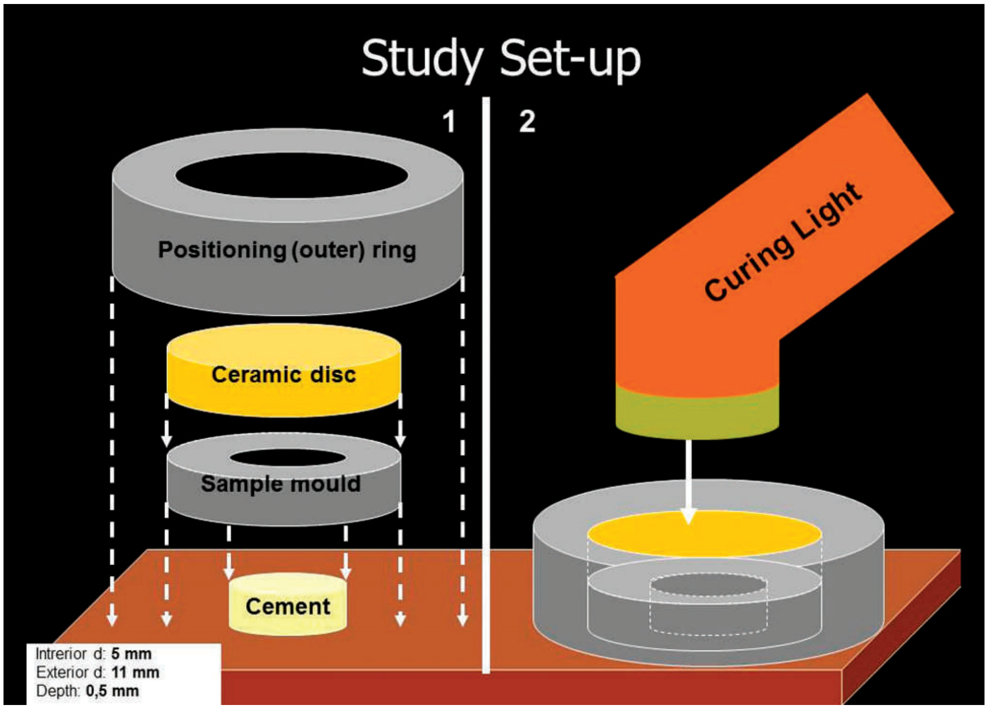

Figure 2. *Resin cement sample dimensions and preparation.*

Following the polymerization procedure, resin cement samples were labeled and stored inside their sample molds in an incubator (VWR Signature Incubator, VRW Inc, West Chester, PA, USA) at 37°C in deionized water for 24 hours to complete the delayed polymerization before testing.

Vickers microhardness measurements were performed from the bottom surface of the resin cement sample from three different locations under 30 g of load and 15 seconds of indentation time (Micromet, Buehler) at 24 hours.

A total of 1530 microhardness readings were recorded. Single-use sample molds facilitated clear marking of each sample and eliminated any sample or surface confusion. Figure 3 shows the clearly marked resin cement sample and the placement of the sample during the microhardness testing.

Data were analyzed using analysis of variance. a full factorial fixed effects model was used to determine the significance of the ceramic thicknesses and shade on polymerization. Tukey *post hoc* analysis was used to rank the significant variables.

RESULTS

Light transmission values of various ceramic discs are displayed in Table 2. Transmission was decreased with darker shade or thicker ceramic. The amount of transmitted light had a statistically significant effect on the measured microhardness values (p=0.000).

Microhardness of different resin cements polymerized through various shades and thicknesses of ceramic was measured. Ceramic shade had a statistically significant effect on only two resin cement groups and, coincidentally, on different polymerization types of the same resin brand (p=0.029). In LC cements, Calibra LC had significantly lower microhardness values when polymerized through ETC2 shade ceramic ($p<0.001$). In DC resin cements, Calibra DC group polymerized through ETC3 and ETC4 shades of ceramic had significantly lower microhardness values compared to groups polymerized through ETC1 shade ceramic ($p<0.001$). However, in both groups that were affected by the ceramic shade, statistical significance was observed only when the ceramic thickness was increased to 3 and 4 mm ($p<0.0001$).

Ceramic thickness had a significant effect on microhardness values of all of the resin cement groups ($p<0.0001$).

In LC resin cements, in Nexus 2 LC, resin samples polymerized through 3-mm ceramic thickness had significantly lower microhardness values compared to the samples polymerized through 1-mm ceramic thickness ($p<0.0001$). Similarly, samples polymer-

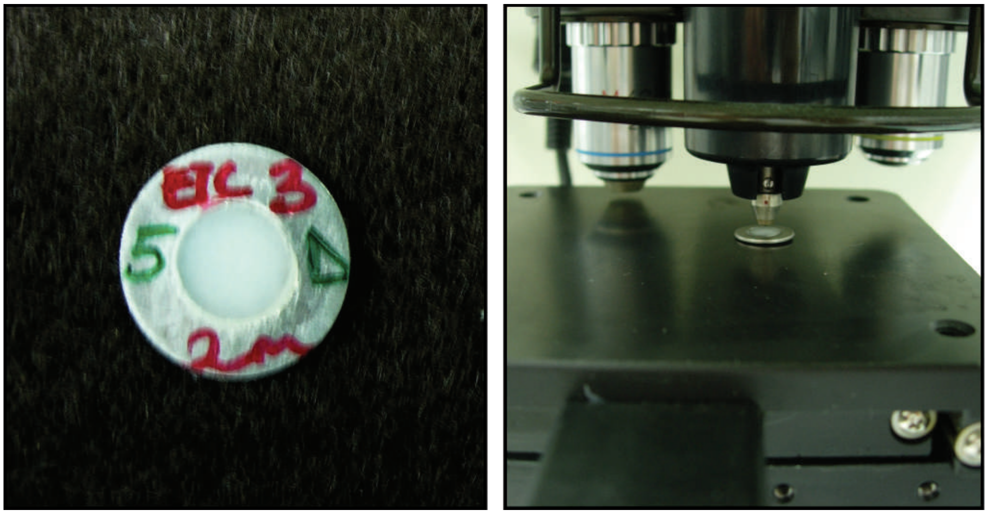

Figure 3. *Resin cement sample polymerized and stored inside the sample mold. This mold facilitated easy identification of this dual cure resin cement sample polymerized under 2-mm thick ETC3 shade ceramic (left) and also provided sample stabilization during the Vickers microhardness testing (right).*

ized through 4-mm ceramic thickness had significantly lower microhardness compared to the rest of the samples within the group ($p<0.0001$). In Calibra LC, resin samples polymerized through 3- and 4-mm ceramic thicknesses had significantly lower microhardness values compared to the samples polymerized through 1- and 2-mm ceramic thicknesses ($p<0.0001$). In Appeal LC, only 3-mm ceramic thickness had a significantly different adverse effect on microhardness ($p<0.0001$). Results are displayed in Table 3.

In DC resin cements, in the groups Nexus 2 DC and Calibra DC, resin samples had significantly lower microhardness values when polymerized through 3- and 4-mm ceramic thicknesses compared to the 1- and 2-mm ceramic thicknesses ($p<0.0001$).

Table 2: *Light Transmittance Values (mW/cm^2) for Various Thicknesses and Shades of Ceramic Ingot Discs*

Shade	1 mm	2 mm	3 mm	4 mm	Control
ETC1	400	250	175	100	-
ETC2	375	200	125	80	-
ETC3	350	180	100	60	-
ETC4	325	190	100	60	-
Control	-	-	-	-	800

In Appeal DC, the only significance was between resin samples polymerized through 1-mm ceramic and samples polymerized through 4-mm ceramic thickness ($p<0.001$). Results are displayed in Table 4.

The polymerization type of resin cement had a statistically significant effect on microhardness values ($p<0.0001$). The effect of ETC1 shade ceramic thickness on LC and DC cements is displayed in Figure 4.

The critical ceramic thickness that adversely affects resin cement microhardness was determined as 3 mm for both polymerization types.

DISCUSSION

Resin cements have been the most commonly used type of luting agent in the cementation of all-ceramic restorations.[10] This study evaluated only LC and DC resin cements and excluded auto-cure resin cements due to their limited use in a clinical setting.[20] Unlike auto-cure resin cements, LC and DC resin cements need adequate light for optimal polymerization.[7,10] Light transmission of restorations is even more critical for the polymerization of LC resin cements since all they can utilize is the transmitted amount of the light.[15,21] In the use of DC cements, it may be assumed that the chemical component of the cement may compensate for the decreased light transmission. Nevertheless, it was demonstrated that the chemical component of DC resin cements cannot be sufficient alone to enable maximum monomer conversion.[1,20,22] According to the results of this study,

Table 3: *Light-cure Resin Cement Microhardness Values (Standard Deviation)**

Ceramic Shade[a]	Ceramic Thickness[b]	Nexus 2 LC	Calibra LC	Appeal LC
ETC1	1 mm	24.5 (1.9)	20.5 (1.1)	14.3 (1.0)
	2 mm	22.3 (2.3)	18.2 (1.1)	14.7 (1.2)
	3 mm	22.0 (1.2)	15.0 (0.8)	14.3 (1.2)
	4 mm	18.8 (2.2)	13.0 (0.9)	14.3 (1.0)
ETC2	1 mm	24.3 (1.6)	18.8 (1.0)	16.3 (1.8)
	2 mm	22.4 (1.9)	16.2 (1.2)	15.0 (0.9)
	3 mm	21.0 (1.9)	11.5 (1.2)	13.9 (0.8)
	4 mm	18.7 (1.6)	9.5 (1.0)	13.0 (0.8)
ETC3	1 mm	25.2 (1.8)	18.0 (0.5)	15.6 (1.0)
	2 mm	24.0 (1.6)	18.1 (1.6)	14.5 (0.8)
	3 mm	21.6 (2.3)	16.7 (0.7)	14.5 (1.2)
	4 mm	15.2 (1.2)	15.8 (0.7)	13.8 (1.5)
ETC4	1 mm	24.0 (1.6)	18.1 (0.7)	15.6 (0.9)
	2 mm	22.2 (1.5)	17.5 (0.4)	15.7 (3.1)
	3 mm	19.1 (1.2)	16.6 (0.4)	14.0 (1.4)
	4 mm	17.7 (1.0)	16.0 (0.4)	13.7 (1.6)
Control / No Ceramic		25.8 (0.8)	22.7 (0.8)	17.4 (0.7)

** Statistical significance ($p<0.01$).*
[a] Ceramic shade: Calibra LC: ETC2 vs all other shades at 3 mm; ETC2 vs all other shades at 4 mm.
[b] Ceramic thickness: Nexus 2 LC: 3 mm vs 1 mm; 4 mm vs 1 mm; 4 mm vs 2 mm; 4 mm vs 3 mm. Calibra LC: 3 mm vs 1 mm; 3 mm vs 2 mm; 4 mm vs 1 mm; 4 mm vs 2 mm. Appeal LC: 3 mm vs 1 mm; 3 mm vs 2 mm; 3 mm vs 4 mm.

Table 4: *Dual-cure Resin Cement Microhardness Values (Standard Deviation)*

Ceramic Shade[a]	Ceramic Thickness[b]	Nexus 2 DC	Calibra DC	Appeal DC
ETC1	1 mm	30.8 (2.0)	32.4 (1.2)	24.9 (2.4)
	2 mm	29.3 (1.8)	29.4 (1.4)	24.6 (3.0)
	3 mm	29.9 (2.5)	27.9 (1.3)	26.4 (2.0)
	4 mm	27.3 (1.6)	27.6 (1.3)	22.7 (2.0)
ETC2	1 mm	32.6 (1.5)	31.0 (1.6)	25.4 (1.3)
	2 mm	31.4 (1.6)	27.6 (1.0)	24.9 (1.5)
	3 mm	30.3 (1.8)	26.9 (1.1)	24.4 (3.3)
	4 mm	29.4 (2.0)	26.3 (1.0)	24.0 (3.1)
ETC3	1 mm	32.5 (1.2)	29.0 (0.6)	28.2 (2.0)
	2 mm	31.5 (1.6)	28.6 (2.3)	27.2 (1.9)
	3 mm	29.9 (1.7)	25.8 (0.7)	23.4 (1.0)
	4 mm	24.5 (1.1)	25.1 (0.7)	22.3 (2.0)
ETC4	1 mm	30.5 (0.9)	28.7 (0.5)	25.0 (1.6)
	2 mm	30.1 (0.7)	28.3 (1.2)	24.4 (1.7)
	3 mm	29.6 (1.2)	25.7 (0.5)	24.4 (2.1)
	4 mm	27.8 (1.6)	25.0 (0.5)	24.3 (1.9)
Control / No Ceramic		34.2 (0.8)	35.1 (0.7)	29.9 (1.0)

** Statistical significance ($p<0.01$).*
[a] Ceramic shade: Calibra DC: ETC3 vs ETC1 at 3 mm; ETC3 vs ETC1 at 4 mm; ETC4 vs ETC1 at 3 mm; ETC4 vs ETC1 at 4 mm.
[b] Ceramic thickness: Nexus 2 DC: 3 mm vs 1 mm; 3 mm vs 2 mm; 4 mm vs 1 mm; 4 mm vs 2 mm. Calibra DC: 3 mm vs 1 mm; 3 mm vs 2 mm; 4 mm vs 1 mm; 4 mm vs 2 mm. Appeal DC: 1 mm vs 4 mm.

the polymerization of DC resin cements was negatively affected from the decreased light transmission similar to the LC resin cements.

The translucency of all-ceramic restorations depends on their crystalline structure, light refractive index, and thicknesses.[10,16,20,23] Relatively opaque core material underneath the veneering material is necessary for strength and it is shown to affect light transmission especially on the body of the ceramic restoration.[16] This study utilized more opaque ingot discs without the use of more translucent veneering ceramic to evaluate the effect of opacity and to minimize the variability. One study has shown that 1-mm glass transmits 13 times more light compared

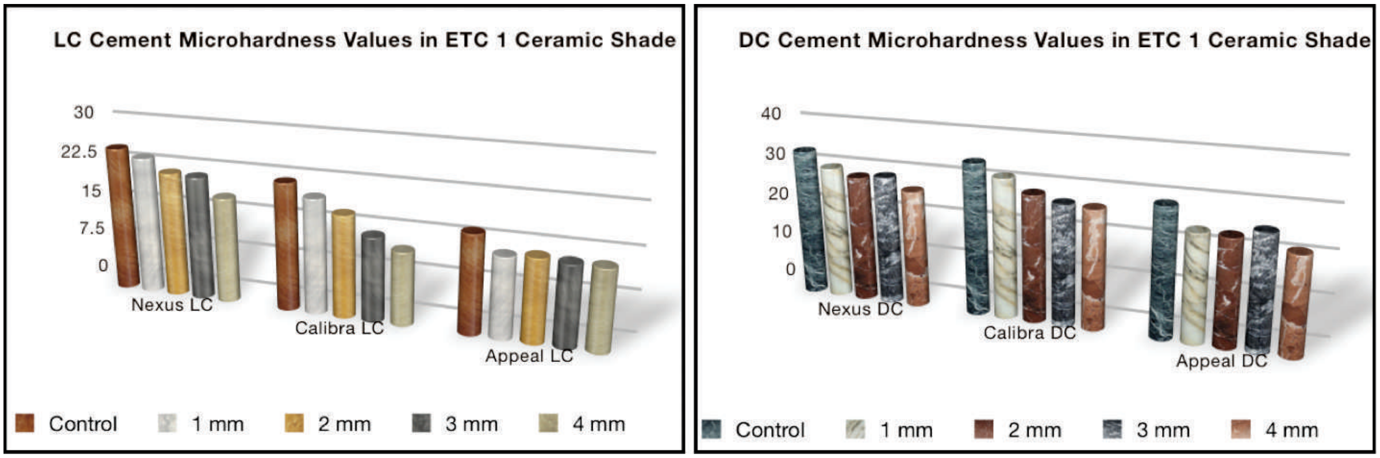

Figure 4. *Microhardness values of LC (left) and DC (right) resin cements cured under various thicknesses of ETC1 shade ceramic.*

to 1-mm thick IPS Empress veneering ceramic.[16] In the clinical setting, a great portion of the anterior all-ceramic restorations need to be thicker than 1 mm. The thickness of an anterior restoration may be generally around or below 1 mm on the facial and lingual surfaces. Nevertheless, the ceramic thickness may increase to 1.5 to 2 mm on the incisal edge. A posterior inlay/onlay restoration has to be at least 1.5 to 2 mm thick, but the ceramic thickness may increase up to 3 to 4 mm in the proximal box.[1,5,12,15,24] This study tested the effect of ceramic thickness in all of these scenarios. The results showed that ceramic thickness has an intense effect on resin microhardness and light transmission and therefore agreed with other studies that show a logarithmic decrease.[18,25] Among the three resins from three different manufacturers, only one resin (Calibra) was significantly influenced by the shade of the ceramic (ETC3). In both LC and DC types of that particular resin, polymerization was adversely affected only when the ceramic thickness was 3 mm and above. This certain thickness gave a yellow-brown hue to the ETC3 shade. In the remaining two other resin cement groups, ceramic shade did not have any effects.

There are no specific curing times for different thickness and shade of ceramics stated by the manufacturers. Generally, a 40-second curing with a 400 mW/cm^2 light intensity is accepted to provide adequate monomer conversion when applied directly on the material.[3] Most dentists implement this curing time on their routine cementation procedures under the ceramics. Therefore, this certain curing protocol is very rarely modified with consideration to the properties of the ceramic or the curing light. This study followed that general use and used 40-second standard curing for all samples even if the light intensity of the LED curing light was measured at 800 mW/cm^2. Some studies suggest increasing the curing times to make up for the decreased light transmission.[15] Nevertheless, there are some studies showing that a higher intensity light source or a longer curing time may not completely overcome the problem of inadequate light transmission.[5]

Microhardness is one of the acceptable methods in the evaluation of resin polymerization together with depth of penetration and infrared spectroscopy.[12] The microhardness method was preferred over the depth of cure testing because it was shown to be a more reliable method when the sample thickness was as low as 0.5 mm. The reason to use a 0.5-mm resin cement sample thickness was to simulate the clinical situations. Testing was performed from the bottom portion of the sample, away from the light source to represent the tooth-cement interface.

The filler amount, type, size, and composition of the resin affect the microhardness values.[26] A higher numerical value on a certain resin group does not show that that particular resin reached a higher degree of polymerization. Therefore, the large differences in the numerical values of microhardness results between different resin cements do not have any clinical relevance. Each resin and its polymerization types were evaluated separately, and the numerical values were compared within only that test group. The only comparison was between how each resin was affected by variables such as ceramic shade, thickness, and light transmission.

It is generally accepted that resins require 400 mW/cm^2 of light intensity for 40 seconds of exposure to generate 16,000 mJ of energy that ensures proper polymerization and resultant clinical success.[2,27] In this study only the 1-mm thickness of ETC1 shade ceramic allowed 400 mW/cm^2 of light intensity. In darker shades, 3 and 4 mm of ceramics had decreased light transmissions as low as 100 and 60 mW/cm^2. The resin groups cured through thicker ceramics were possibly far from reaching adequate energy levels. That may be the reason for the approximately 60%-70% decrease in microhardness values compared to their control groups. It is difficult to correlate a certain numerical value of hardness with clinical success, but a significant decrease in both light transmission and hardness values in a study group can be interpreted as a negative effect on clinical performance. This study showed statistical significance and direct correlation between the decreased light transmission of a 3-mm ceramic thickness and lower resin microhardness results.

Within the limitations of this study, a 3 mm and above ceramic thickness was shown to adversely affect the microhardness values in all of the tested resin cements. Both LC and DC resin cements reached a significantly higher polymerization up to 3 mm of thickness of ceramic. This study's safety range is therefore slightly higher than other reported studies because, generally, the recommended ceramic thickness is 1.5 mm and less for LC cements and 2.5 mm and less for DC resin cements.[5–8,28]

CONCLUSION

Ceramic thickness has a more profound effect on light transmission and resin cement polymerization compared to ceramic shade. Ceramic shade of a yellow-brown hue had an unfavorable effect on polymerization of only one resin when the ceramic thickness was increased. Overlying ceramic thickness of 3 mm and above was found to adversely affect the polymerization of LC and DC resin cements, and therefore 3-mm ceramic thickness was considered the critical threshold. More studies are necessary to test different types of ceramics with various translucencies with various light curing protocols.

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