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Research Article

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Light transmittance of CAD/CAM ceramics with different shades and thicknesses and microhardness of the underlying light-cured resin cement

Zahra Jafari [1], **Homayoon Alaghehmand** [2*], **Yasaman Samani** [3], **Mina Mahdian** [4], **Soraya Khafri** [5]

[1]Department of Restorative Dentistry, Dental Faculty, Mazandaran University of Medical Sciences, Sari, Iran
[2]Dental Materials Research Center, Institute of Health, Babol University of Medical Sciences, Babol, Iran
[3]Department of Restorative Dentistry, Dental Faculty, Semnan University of Medical Sciences, Semnan, Iran
[4]Department of Prosthodontics and Digital Technology, Stony Brook University School of Dental Medicine, Stony Brook, NY, USA
[5]Department of Biostatistics and Epidemiology, Faculty of Medicine, Babol University of Medical Sciences, Babol, Iran

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Jafari Z, Alaghehmand H, Samani Y, Mahdian M, Khafri S

***Correspondence to**
Homayoon Alaghehmand, DDS, MSc
Associate Professor, Dental Materials Research Center, Institute of Health, Babol University of Medical Sciences, Felestin Street, Velayat Square, Babol 4717643633, Iran.
E-mail: halagheh@yahoo.com

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Conflict of Interest
No potential conflict of interest relevant to this article was reported.

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ABSTRACT

Objectives: The aim of this *in vitro* study was to evaluate the effects of the thickness and shade of 3 types of computer-aided design/computer-aided manufacturing (CAD/CAM) materials.
Materials and Methods: A total of 120 specimens of 2 shades (A1 and A3) and 2 thicknesses (1 and 2 mm) were fabricated using VITA Mark II (VM; VITA Zahnfabrik), IPS e.max CAD (IE; IvoclarVivadent), and VITA Suprinity (VS; VITA Zahnfabrik) (n = 10 per subgroup). The amount of light transmission through the ceramic specimens was measured by a radiometer (Optilux, Kerr). Light-cured resin cement samples (Choice 2, Bisco) were fabricated in a Teflon mold and activated through the various ceramics with different shades and thicknesses using an LED unit (Bluephase, IvoclarVivadent). In the control group, the resin cement sample was directly light-cured without any ceramic. Vickers microhardness indentations were made on the resin surfaces (KoopaPazhoohesh) after 24 hours of dark storage in a 37°C incubator. Data were analyzed using analysis of variance followed by the Tukey *post hoc* test ($\alpha = 0.05$).
Results: Ceramic thickness and shade had significant effects on light transmission and the microhardness of all specimens ($p < 0.05$). The mean values of light transmittance and microhardness of the resin cement in the VM group were significantly higher than those observed in the IE and VS groups. The lowest microhardness was observed in the VS group, due to the lowest level of light transmission ($p < 0.05$).
Conclusion: Greater thickness and darker shades of the 3 types of CAD/CAM ceramics significantly decreased the microhardness of the underlying resin cement.

Keywords: Ceramics; Curing lights, dental; Hardness; Resin cements

INTRODUCTION

Over the years, dentistry has evolved into a profession with a growing demand for esthetic restorations, mainly in the form of ceramic restorations [1,2]. Due to the several advantages of ceramic materials, including their natural appearance, fluorescence, biocompatibility,

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ORCID iDs
Zahra Jafari
https://orcid.org/0000-0002-2335-3306
Homayoon Alaghehmand
https://orcid.org/0000-0002-5319-0309
Yasaman Samani
https://orcid.org/0000-0002-2381-212X
Mina Mahdian
https://orcid.org/0000-0002-1814-3574
Soraya Khafri
https://orcid.org/0000-0002-2398-7560

durability, chemical stability, high compressive resistance, and thermal expansion comparable to tooth structure, their application has grown exponentially [1-5]. These restorations can be fabricated via traditional laboratory procedures or computerized approaches. Currently, several ceramic-based esthetic monolithic computer-aided design/computer-aided manufacturing (CAD/CAM) materials are available in the market; these materials can be fabricated within a few minutes, chairside, using CAD/CAM technology [6-10]. However, industrially fabricated materials are considered to have minimal flaws and superior mechanical properties, making them favorable restorative materials for long-term restorations [11-14]. Variation in the composition and crystal content of these materials affects their light transmittance properties, resulting in the development of various resin activation processes.

Among the available reinforced ceramics, VITA Mark II (VITA Zahnfabrik, Bad Säckingen, Germany), IPS e.max CAD (IvocularVivadent, Schaan, Liechtenstein), and VITA Suprinity (VITA Zahnfabrik) are the most commonly used. VITA Mark II is a monochromatic CAD/CAM feldspathic ceramic with outstanding esthetic properties composed of leucite (potassium alumina silicate glass), and is available in multiple shades [11,15,16]. VITA Mark II is used for the fabrication of veneers, inlays/onlays, and single anterior and posterior crowns [17,18]. IPS e.max CAD is a lithium disilicate ceramic that is available in blocks of A–D shades and in a bleach shade, as well as in 3 translucencies (1 with medium opacity). The blue state is the state before crystallization in which IPS e.max CAD blocks can be easily milled [19]. IPS e.max CAD is suggested to be utilized for the fabrication of inlays/onlays, veneers, anterior and posterior crowns, and implant-supported crowns [20,21]. VITA Suprinity is a new generation of lithium disilicate glass ceramic that is enriched with zirconia (approximately 10% by weight) and is available in a pre-crystallized state. These blocks are available in A–D shades and 2 translucencies, and are commonly used for fabrication inlays/onlays, anterior and posterior crowns, and implant-supported crowns [6].

In addition to the restorative material, the luting agent plays a key role in the esthetic properties and the longevity of CAD/CAM restorations [1,3,5,6,22]. Resin cements are generally used in the cementation of all ceramic restorations because of their advantages, which include low solubility, high bond strength,high esthetic suitability, and excellent mechanical properties that reinforce the ceramic restoration. Based on their activation mode, resin cements are classified as chemical-activated, photo-activated, or dual-activated [23-26]. In addition to the instantaneous polymerization of light-cured resin cements, elimination of the spatulation step results in reduced air inclusion into the cement, causing improved color stability and making these types of cements more suitable for veneer restorations [24,27,28]. However, it is important to ensure adequate light transmission through the porcelain veneer to polymerize the light-curedluting agent. Several parameters affect the polymerization of resin cement, including the thickness, shade, and translucency of the ceramic; the type of polymerization; and the resin cement composition [1,3,5,23]. Incomplete cement polymerization can adversely affect its physical and biological properties, including surface hardness, color stability, toxicity from residual monomers, and bond strength between the tooth and the ceramic restoration [27-31]. Surface hardness is an indicator used to evaluate the efficiency of polymerization, and is intertwined with the light intensity applied during polymerization activation.

Numerous studies have investigated the effects of ceramics on the mechanical properties of underlying resin cements [1,3,5,6,22-25] using different types of resin cements [1,22-24], shades [1,5], and light-curing units [25,32]. However, to the best of our knowledge, there is no evidence regarding the correlation between light transmission through various types of CAD/CAM ceramics and the microhardness of the underlying resin cement. Therefore, the aim of this study was to evaluate the light transmittance of various ceramics in different shades and thicknesses and the microhardness of the underlying light-cured resin cement. The null hypotheses were that there would be no difference in the light transmittance of various ceramics with different thicknesses and shades and that there would be no difference in the microhardness of resin cements polymerized through various ceramics with different shades and thicknesses.

MATERIALS AND METHODS

Sample preparation

Three types of chairside CAD/CAM ceramics were analyzed in this study: feldspathic ceramic, VITA Mark II (VM; VITA Zahnfabrik); lithium disilicate glass ceramic, IPS e.max CAD (IE; IvoclarVivadent); zirconia-reinforced lithium disilicate glass ceramic, VITA Suprinity (VS; VITA Zahnfabrik) (**Table 1**).

VITA shades A1 and A3 were selected for all ceramics, and low-translucency shades were selected for IPS e.max CAD and VITA Suprinity. Each ceramic block was sectioned using a slow-speed saw (Delta Precision Sectioning Machine, Mashhad, Iran) under copious irrigation to yield ceramic discs that were 1 and 2 mm thick, with a diameter of 10 mm. The ceramic samples were polished using 400, 600, 800, and 1,200 grit silicon carbide papers. A digital caliper (Shinwa Digital Caliper, Niigata, Japan) was used to confirm the thickness of each disc. All ceramic specimens were crystallized and glazed on 1 side (10 minutes, 950°C for VM; 13 minutes, 840°C for IE; and 12 minutes, 840°C for VS) and conditioned with 5% hydrofluoric acid (60 seconds for VM and 20 seconds for IE and VS) on the other side, according to the manufacturers' instructions. The discs were ultrasonically cleaned for 5 minutes in 99% ethanol to eliminate any oil or dirt contamination, and the final thickness of the specimens was 1 ± 0.05 mm and 2 ± 0.05 mm.

Photometry

The LED curing light unit used in this study was Bluephase C8 (IvocularVivadent). The light transmittance value for each ceramic disc thickness and shade was measured by placing the disc on the aperture of the radiometer (Optilux, Kerr, Orange, CA, USA) and recording the average light intensity through the disc in mW/cm^2.

Microhardness test

A translucent light-cured luting resin (Choice 2, Bisco, Schaumburg, IL, USA) was applied on a Teflon mold with a central hole measuring 5 mm in diameter and 0.5 mm in depth. Mylar strips were placed on the top of the cement to provide isolation during polymerization. A silane

Table 1. List of the materials used in this study

Material	Brand name	Manufacturer	Composition
Feldspathic ceramic	VITABLOCS Mark II	VITA Zahnfabrik, Bad Säckingen, Germany	SiO_2, Al_2O_3, Na_2O, K_2O, CaO, TiO_2
Lithium disilicate ceramic	IPS e.max CAD	IvoclarVivadent, Schaan, Liechtenstein	SiO_2, Li_2O, K_2O, P_2O_5, ZrO_2, ZnO, Al_2O_3, MgO
Zirconia-reinforced lithium disilicate ceramic	VITA Suprinity	VITA Zahnfabrik, Bad Säckingen, Germany	SiO_2, Li_2O, ZrO_2, K_2O, P_2O_5, Al_2O_3, CeO_2
Light-cured resin cement	Choice 2	Bisco, Schaumburg, IL, USA	Strontium glass, amorphous silica, Bis-GMA

Bis-GMA, bisphenol A-glycidyl methacrylate.

coupling agent (Bis-silane, Bisco) was then applied to each ceramic disc, followed by a porcelain bonding agent (Porcelain Bonding Resin, Bisco) with a 30-second time lapse to simulate clinical conditions. The resin cements were polymerized through prepared ceramic discs for 40 seconds with the LED curing unit held in direct contact with the ceramic. The output of the curing light was continuously monitored, and the average output was measured as 800 mW/cm^2. In the control group, the resin cement was directly polymerized under a Mylar strip without the presence of ceramic. All resin cement samples were ground to eliminate the superficial resin-rich layer in contact with the Mylar strip using 600, 800, and 1,200 grit silicon carbide sandpaper. Following the polymerization procedure, the resin cement samples were labeled and stored inside the sample molds in an incubator at 37°C in deionized water for 24 hours to complete the delayed polymerization prior to testing. The combination of all parameters rendered a total of 12 groups, each containing 10 ceramic discs and 10 resin cements ($n = 10$). The 3 ceramic materials included 4 subgroups (2 ceramic shades × 2 ceramic thicknesses) each. A total of 120 resin cement samples were fabricated, and a total of 360 microhardness readings were recorded. Additionally, the microhardness of 1 resin cement sample in the control group was recorded to register the maximum Vickers hardness number. Vickers measurements were performed from the top of the resin cement samples by 3 different indentation points with at least 1 mm distance under a load of 50 g and 10 seconds of indentation time (KoopaPazhoohesh, Sari, Iran). The average value of the 3 readings for each sample was recorded as the Vickers hardness number.

Data were analyzed using multivariate analysis of variance (ANOVA). Tukey *post hoc* analysis was used to rank the significant variables. The p values less than 0.05 were considered to indicate statistical significance (SPSS version 17.0, SPSS Inc., Chicago, IL, USA).

RESULTS

Photometry

Light transmittance was significantly lower in all the experimental groups than in the direct light activation group (control group). The results of 3- and 2-way ANOVA indicated no interactions between 3 and 2 factors. **Table 2** presents the significant differences among the different types of ceramics ($p < 0.001$ for all). Light transmission decreased significantly with darker shades and increased ceramic thickness ($p < 0.001$ for all).

Microhardness

The results of the Vickers microhardness test are displayed in **Table 3**. Microhardness values were significantly lower in all experimental groups than in the control group. The results of 3- and

Table 2. Light transmittance values (mW/cm^2) for various types, thicknesses, and shades of computer-aided design/computer-aided manufacturing (CAD/CAM) ceramics

CAD/CAM material	A1		A3	
	1 mm	2 mm	1 mm	2 mm
VITA Mark II	320.0 ± 8.2^{a*†}	205.8 ± 5.8^{a*}	261.3 ± 19.5^{a†}	128.4 ± 7.9^{a}
IPS e.max CAD	253.0 ± 8.2^{b*†}	108.1 ± 4.3^{b*}	212.4 ± 8.1^{b†}	83.3 ± 5.0^{b}
VITA Suprinity	216.1 ± 5.8^{c*†}	98.4 ± 6.0^{c*}	163.5 ± 9.3^{c†}	63.7 ± 7.8^{c}
Control	800.0			

Data are presented as mean ± standard deviation ($n = 10$). Different superscript lowercase letters indicate that there were statistically significant differences within each column.
*Indicates that there was a statistically significant difference in each thickness between 2 shades ($p < 0.05$); †indicates that there was a statistically significant difference in each shade between 2 thicknesses ($p < 0.05$).

Table 3. Vickers microhardness numbers of choice 2 resin cement under various types, thicknesses, and shades of computer-aided design/computer-aided manufacturing (CAD/CAM) ceramics

CAD/CAM material	A1		A3	
	1 mm	2 mm	1 mm	2 mm
VITA Mark II	44.1 ± 1.3[a*†]	31.2 ± 0.6[a*]	36.3 ± 1.5[a†]	25.9 ± 0.2[a]
IPS e.max CAD	36.3 ± 0.9[b*†]	22.1 ± 1.5[b*]	31.2 ± 0.7[b†]	20.4 ± 0.5[b]
VITA Suprinity	32.7 ± 1.0[c*†]	18.5 ± 1.0[c*]	28.0 ± 0.7[c†]	16.7 ± 0.5[c]
Control	78.6			

Data are presented as mean ± standard deviation (n = 10). Different superscript lowercase letters indicate that there were statistically significant differences within each column.
[*]Indicates that there was a statistically significant difference in each thickness between 2 shades ($p < 0.05$); [†]indicates that there was a statistically significant difference in each shade between 2 thicknesses ($p < 0.05$).

2-way ANOVA showed no interactions between 3 and 2 factors. As shown in **Table 3**, significant differences were observed among ceramics of similar shades and thicknesses ($p < 0.001$ for all). The mean microhardness of the resin cements in the VM group was significantly higher than in the IE and VS groups due to higher light transmission. The microhardness numbers of the resin samples in the VS group were inferior to those in the IE and VM groups. Ceramic thickness and shade had significant influences on microhardness values in all types of ceramics.

DISCUSSION

Resin cements are commonly used for the cementation of all ceramic restorations [1,22,23,25]. Optimal resin polymerization under different thicknesses and shades of ceramic restorations results in high bond strength between the tooth and the restoration, making it a key element in ensuring the longevity of a restoration [1,5,6]. Therefore, the micromechanical properties of the material can be a significant factor affecting the clinical outcomes of a restoration [5,33].

In the present study, all specimens showed statistically significantly lower light transmission compared to the direct light activation group (control group), and the highest light transmittance was measured beneath feldspathic ceramic VM. The lowest values were recorded for zirconia-reinforced glass ceramic VS, followed by lithium disilicate glass ceramic IE. Our findings demonstrated that 58.2%–88.7% of the light was lost as it traveled through the initial 1-mm-thickness of the specimen, and this range increased to 64.4%–94.0% for 2-mm-thick ceramic discs. Therefore, longer irradiation times are recommended to compensate for the reduced light as it travels through the ceramic restoration. These results are in agreement with the study conducted by Stawarczyk *et al.* [6]. The translucency of all ceramic restorations and the transmitted light are dependent on the crystalline structure, grain size, pigments, volume and distribution of defects, and porosity [6,34]. Our findings are in line with those of a previous study in which lower light transmittance values were observed for lithium disilicate glass ceramics, which was attributed to different microstructures and the presence of denser crystals in lithium disilicate than in feldspathic ceramic [6]. In lithium disilicate glass ceramics, the main crystalline phase, which constitutes about 65% of the volume, consists of elongated lithium disilicate ($Li_2Si_2O_5$) crystals that form a scaffold of numerous small interlocking needle shapes and randomly oriented crystals [2,6,34-37]. In contrast, the microstructure of VM is less dense and is made up of sanidine ($KAlSi_3O_8$)-reinforced feldspathic ceramic with a crystalline content of about 30% [38]. Additionally, ceramics with higher crystalline content, such as VS, tend to be less translucent. The inclusion of zirconium oxide crystals into lithium disilicate glass ceramic

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may reduce the light transmittance, as zirconium compounds cause the ceramic to appear dull and opaque [39]. This observation may explain why the use of dual-cured resin cement is recommended for some zirconia- and alumina-based ceramics.

The specimens in the present study were prepared in thicknesses and shades that resembled clinical conditions. For instance, in an anterior restoration, the thickness of the ceramic may be around 1 mm at the margins, potentially increasing to 1.5–2 mm on the incisal edge or cuspal areas [3,6,23,24,32,40]. Furthermore, the curved contours of the restoration limit optimal contact between the light source and the restoration; thus, our findings suggest that the resin cement is likely to set well along the margins, but will not reach complete strength and hardness beneath the cuspal areas.

Energy loss in the first 1 mm of all 3 specimens was notably higher than in the 2-mm specimens. Accordingly, our results demonstrated that the resin cement in deeper layers received less light intensity in areas with a greater thickness and darker shade. This finding is in line with previous studies [5,6,19,23]. Thus, to achieve optimum light penetration and resin cement polymerization, accurate knowledge of the correlation between light transmittance and thickness of the resin cement for different shades is fundamental in order to improve the long-term stability of ceramic restorations.

Similar to resin composites, resin cements are composed of methacrylate or bisphenol A-glycidyl methacrylate. Light-cured resin cements have a photoinitiator, primarily camphorquinone. The polymerization process begins when the photoinitiator is activated by the light from the light-curing unit [1]. Incomplete polymerization of the restorative material will affect its physical properties, including surface hardness [1,26,28]. Surface hardness is a parameter used to evaluate resin polymerization [1,23] by measuring the surface resistance of material to plastic deformation by penetration [5,35]. To simulate clinical conditions in the present study, the resin cement was prepared in 0.5 mm thicknesses, and in order to reliably measure the surface hardness at this thickness, the microhardness test was preferred over the depth-of-cure test. This study found that directly activated resin cements demonstrated greater surface hardness than those activated through ceramics. Microhardness values were lower in the resin groups cured through thicker ceramics compared to the thinner group, likely because lower energy levels reached the deeper layers of the resin cement. This finding agrees with those of numerous previous studies [5,19,23]. The Vickers microhardness number of the cements under feldspathic ceramics (VM group) was significantly higher that of the IE group, followed by the VS group. This is consistent with higher transmittance values in the VM group than in the IE and VS groups, which likely occurred due to the ceramic microstructure. This finding is in line with that of Borges *et al.* [3], who reported that resin cements polymerized under alumina and zirconia ceramics had lower microhardness than resin cements polymerized under glass ceramics. According to our findings, a prolonged light-curing time may result in improved polymerization of light-cured resin cements. Additionally, dual-cured resin cements, with the advantages of both chemical- and light-cured materials, are valuable luting agents for anterior restorations. However, for the initiation of the polymerization process, adequate light activation is required.

While microhardness values may not be a direct representation of clinical hardness, a significant decrease in light transmission and microhardness values can be interpreted as a negative effect on the clinical performance of the resin cement. This study is limited in that it evaluated 3 types of ceramics, 1 type and shade of resin cement, and 1 type of light curing

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system. Therefore, further research is required to investigate other factors, such as other types of CAD/CAM ceramics in different cementation conditions.

CONCLUSIONS

The present study demonstrated that the shade, thickness, and type of ceramic influenced the microhardness of the underlying resin cement. Therefore, these factors may play a pivotal role in the clinical success of ceramic restorations. Based on this finding, it is recommended to consider using dual-cured resin cements.

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