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Effect of CAD-CAM block thickness and translucency on the polymerization of luting materials

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Abstract

Aim This in-vitro study aimed to evaluate the degree of conversion (DC) of dual-cured luting cement (Bifix QM, VOCO) and flowable composite (Grandio Flow, VOCO) under lithium disilicate glass-ceramic (IPS e.max CAD, Ivoclar Vivadent) and hybrid ceramic (Grandio Blocs, VOCO; Cerasmart, GC) CAD-CAM blocks with different thicknesses.

Materials and methods Contrast ratio (CR), translucency (TP_{ab}, TP_{00}), and opalescence (OP) parameters of 30 disc-shaped CAD-CAM blocks ($n=5$) prepared with two different thicknesses (1.5 and 2 mm) and 8 mm diameters were calculated using a spectrophotometer (VITA Easyshade V, Zahnfabrik). A total of 36 Bifix QM and Grandio Flow samples were prepared at 100 µm thickness using a specific setup by polymerizing from the top of the blocks. Following immersion in distilled water at 37 °C for 24 h, luting materials were examined by Fourier Transform Infrared Spectroscopy for DC calculation. Data were analyzed using One-way ANOVA, Kruskal Wallis, Mann Whitney U, and Independent Samples t-tests ($p<0.05$).

Results It was observed that, as the block thickness increased TP_{ab}, TP_{00}, and OP decreased, while CR increased. There was no significant difference between the DC of Bifix QM and Grandio Flow when 1.5 mm blocks were used in all groups ($p>0.05$). DC of Grandio Flow was significantly higher than Bifix QM under 2 mm-IPS e.max CAD ($p=0.011$).

Conclusion The translucency of the CAD-CAM blocks varies depending on their thickness. However, there was no significant difference in the DC of the luting materials depending on the block thickness. Further studies are needed on the use of flowable resin composites as luting material.

Keywords CAD-CAM block, Degree of conversion, Flowable resin composite, Luting material, Translucency

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Introduction

The use of CAD-CAM restorations in digital dentistry has become increasingly prevalent in recent years, particularly for indirect restorations. Currently, a range of materials such as glass ceramics, zirconia, hybrid ceramics, and resin composites can be used in CAD-CAM restorations [1, 2]. The efficacy of treatment depends on several variables, including the compatibility of colors between the indirect restoration and teeth, the color and thickness of the tooth structure, the thickness, type, and shade of material used, and the luting systems preferred [3, 4]. Restorative materials should replicate the characteristics of teeth, such as opalescence, translucency, and fluorescence to achieve a natural-looking and esthetically pleasing result [5, 6]. While the term opalescence (OP) is used to describe the "bluish-white" appearance of dental materials in reflected light and the "orange and brown" appearance in transmitted light, the term "translucency" is used to define the degree of light transmission or diffusion from the substrate, indicating the material's condition between transparency and opacity. The translucency parameter (TP) is of great importance in esthetics, as it is calculated based on the color difference observed against white and black backgrounds using the color space of Commission Internationale de l'Éclairage (CIE). This method permits a quantitative assessment of translucency [7, 8]. The opalescence and translucency of CAD-CAM indirect restorations can be influenced by many factors such as type and thickness of the material, and surface treatments [9]. All materials possess unique compositions, crystalline contents, microstructures, and phases that can influence their optical properties [10]. It is of paramount importance to consider the impact of material thickness on translucency and opalescence. Multiple studies have shown that translucency values decrease as thickness increases [9, 11, 12]. There are a few methods to calculate translucency, such as Translucency Parameter (TP_{ab}, TP_{00}) and Contrast Ratio (CR). CR is the ratio of the reflectance of a specimen located over a black background to that over a white one with a known reflectance and it is considered as an estimation of opacity. On the other hand, TP measures the color difference of material over black and white backgrounds [13].

In addition to the esthetic appearance, the optical properties, thickness, and type of the preferred restorative materials are considered to be effective on the properties and polymerization of the luting material [14]. Many studies have demonstrated that several factors, namely the type, thickness, and color of the ceramic and also the type of curing mode can influence the complete polymerization process of the luting agent [15–17]. For restoration to be both reliable and long-lasting, it is important to consider the performance of the luting material as well as that of the restorative material. The translucency parameter of the restoration also influences the light transmission and subsequently the degree of conversion of resin cement used [18]. The polymerization of resin-matrix cement under restorations has a significant effect on the mechanical properties of the restorative interface [19]. A decrease in the degree of conversion (DC) can cause an increase in the solubility of resin-based luting materials, potentially leading to microleakage at the margins of restorations [20]. This, in turn, can facilitate the formation of caries, ultimately compromising the integrity of the restoration [21]. A higher DC results in improved physicochemical properties and biocompatibility and is clinically related to a decrease in wear and color stability [22]. It is recommended that self-curing, dual-curing, and light-curing resin cements be used in luting procedures. Additionally, light-cured resin composites are also used for luting indirect restorations because they provide benefits comparable to cements due to longer working time and physical properties such as higher micro-tensile bond strength and color stability [23–25].

This in-vitro study aimed to evaluate the degree of conversion of a light-cured flowable resin composite and dual-cured luting cement under ceramic hybrid and lithium disilicate glass ceramic CAD-CAM blocks with different thicknesses. The null hypotheses were as follows:

1. The opalescence, translucency parameter, and contrast ratio of the blocks are not affected by their thickness.
2. There is no difference in the degree of conversion between light-cured flowable resin composite and dual-cured cement under blocks of the same thickness and type.
3. The degree of conversion of luting materials is not affected by the thickness of the blocks.

Materials and methods

This in-vitro study utilized hybrid and lithium disilicate CAD-CAM blocks (shade A2, low- translucent) together with light-cured flowable resin composite or dual-cured resin cement as luting materials (Table 1). Luting materials and disc-shaped block samples were prepared in this study and the flowchart is illustrated in Fig. 1. The quota sampling method was used to determine the number of samples used in the study, considering the budget and the sample sizes of other studies in the literature [26, 27].

CAD-CAM block preparation

Digital models of disc-shaped CAD-CAM block samples (8 mm diameter) with two different thicknesses of 1.5 and 2 mm were designed with CAD software (SolidWorks, USA). The obtained model was exported in STL format and milled ($n=5$) using an MCX5 Milling Unit (Dentsply

Table 1 Materials and their compositions were used in this study

Materials		Manufacturer	Manufacturer's description	Composition
CAD-CAM Blocks	**IPS e.max CAD LT, A2**	Ivoclar Vivadent, Liechtenstein	Lithium disilicate glass ceramic (CAD-CAM)	70 vol% fine-grain lithium disilicate crystals (SiO_2, Li_2O, K_2O, MgO, P_2O_5, Al_2O_3).
	Cerasmart LT, A2	GC, Japan	Force-absorbing, hybrid ceramic CAD-CAM block	71% silica (20 nm) and barium glass (300 nm) nanoparticles, 29% Bis-MEPP, UDMA, DMA.
	Grandio Blocs LT, A2	VOCO, Germany	Nanoceramic hybrid CAD-CAM block	14% polymer matrix (UDMA and DMA) 86% of nanohybrid fillers (1 µm), functionalized silicon dioxide nanoparticles (20 to 40 nm).
Luting Materials	**Bifix QM shade universal**	VOCO, Germany	Dual-curing universal composite-based luting system	Bis-GMA, benzoyl peroxide, amines, barium-aluminium boron-silicate glass (71–73% wt).
	Grandio Flow shade A2	VOCO, Germany	Flowable universal nano-hybrid restorative material	Bis-GMA, TEGDMA, HEDMA, glass ceramic, nanoparticle (65.6 wt%).

Abbreviations SiO_2 — silicone dioxide, Li_2O— lithium oxide, K_2O—potassium oxide, MgO — magnesium oxide, P_2O_5 — phosphorus pentoxide, Al_2O_3 — aluminum oxide, Bis-MEPP — bisphenol A ethoxylate dimethacrylate

DMA — dimethacrylate, Bis-GMA — bisphenol a diglycidyl ether methacrylate, TEGDMA — triethylenglycol dimethacrylate, HEDMA —hydroxyethyl dimethacrylate

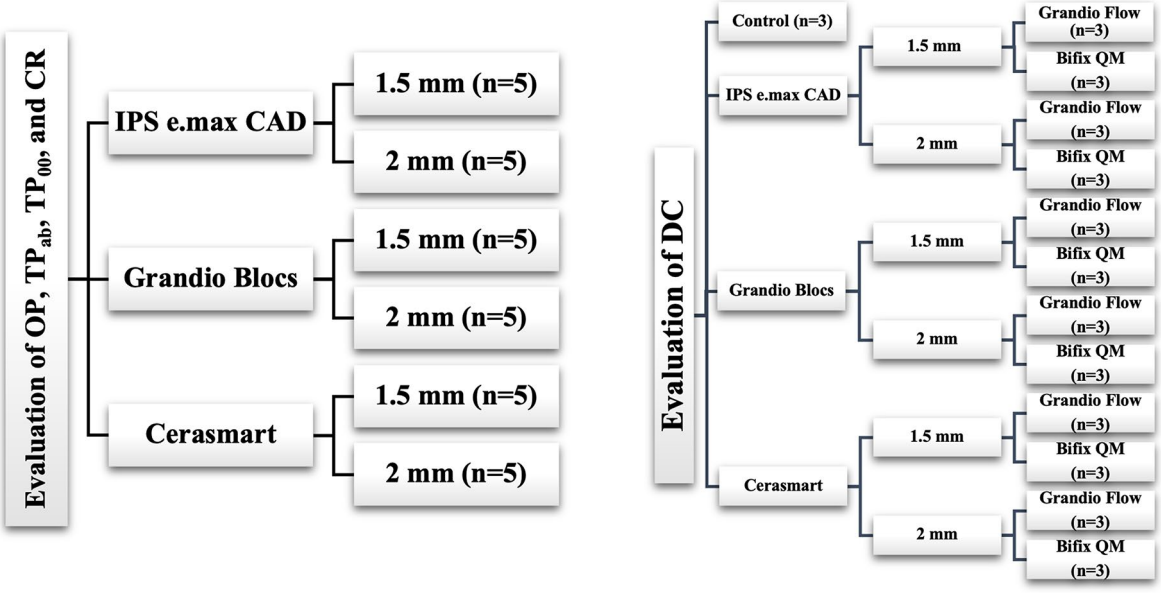


Fig. 1 Flowchart for preparation of each CAD-CAM block and the dual-cured resin cement/light-cured flowable composite samples. OP: opalescence, TP_{ab}: translucency parameter with CIELab formula, TP_{00}: translucency parameter with CIEDE2000 formula, CR: contrast ratio, DC: degree of conversion

Sirona, Germany). Sample thickness was measured with a digital caliper (±0.1 mm). After pre- and fine polishing (OptraFine, Ivoclar Vivadent, Liechtenstein) procedure of the samples, lithium disilicate IPS e.max CAD (Ivoclar Vivadent, Liechtenstein) discs were ultrasonically cleaned in water and subjected to firing for crystallization in a Programat CS ceramic furnace (Ivoclar Vivadent, Liechtenstein) according to the manufacturer's instructions. Following the milling process, the Cersamart (GC, Japan) and Grandio Blocs (VOCO, Germany) hybrid blocks were polished using diamond grinding polishers (Dimanto, VOCO, Germany) as recommended by the manufacturers. Samples were stored in deionized water at 37 °C for 24 h in darkness as specified by the ISO/TR 28642:2016.

Translucency and opalescence

Thirty CAD-CAM block samples' color coordinate values were determined with a spectrophotometer (VITA Easyshade V, Zahnfabrik, Germany) on black and white backgrounds. The translucency of the samples was calculated with the opalescence parameter (OP), contrast ratio (CR), and translucency parameters (TP_{00}, TP_{ab}).

- Primarily, luminance from the color space was calculated using L* coordinates as follows:

$$Y = \left(\frac{L+16}{116}\right)^3 \times \ Y_n$$

Y values were recorded on white (Y_w) and black (Y_b) backgrounds.

- CR was calculated as follows:

$$CR = \frac{Y_w}{Y_b}$$

- TP_{ab} was calculated using the CIEL*a*b* formula:

$$TP_{ab} = \sqrt[2]{(L*_B L*_W)^2 + (a*_B a*_W)^2 + (b*_B b*_W)^2}$$

W and B refer to values on white and black backgrounds, respectively.

- TP_{00} was calculated using the CIEDE2000 formula:

$$TP_{00} = \sqrt[2]{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C';}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)^2\left(\frac{\Delta H'}{K_H S_H}\right)^2}$$

- OP was calculated as follows:

$$OP = \sqrt{(a*_B a*_W)^2 + (b*_B b*_W)^2}$$

W and B refer to values on white and black backgrounds, respectively.

Luting materials preparation

After obtaining the final version of the CAD-CAM samples, light-cured Grandio Flow (VOCO, Germany) and dual-cured Bifix QM (VOCO, Germany) were polymerized through 1.5 and 2 mm thick CAD-CAM blocks. Thirty-six samples (n=3, per material) with standard thicknesses (100 µm) were achieved by placing 2 adhesive tapes (3M, USA) between the glass plate and mylar strip used in this setup. The flowable resin composite and luting cement were polymerized using a polywave LED-curing unit (1000 mw/cm^2, Valo Cordless, Ultradent) for 20 s from the upper surface of the blocks by enclosing the periphery with a silicone mold (Fig. 2.). Sample thickness was measured with a digital caliper (±0.1 mm) and then samples were stored in deionized water at 37 °C for 24 h in darkness. Additional 3 samples of Bifix QM and Grandio Flow were directly polymerized in the setup as a control group.

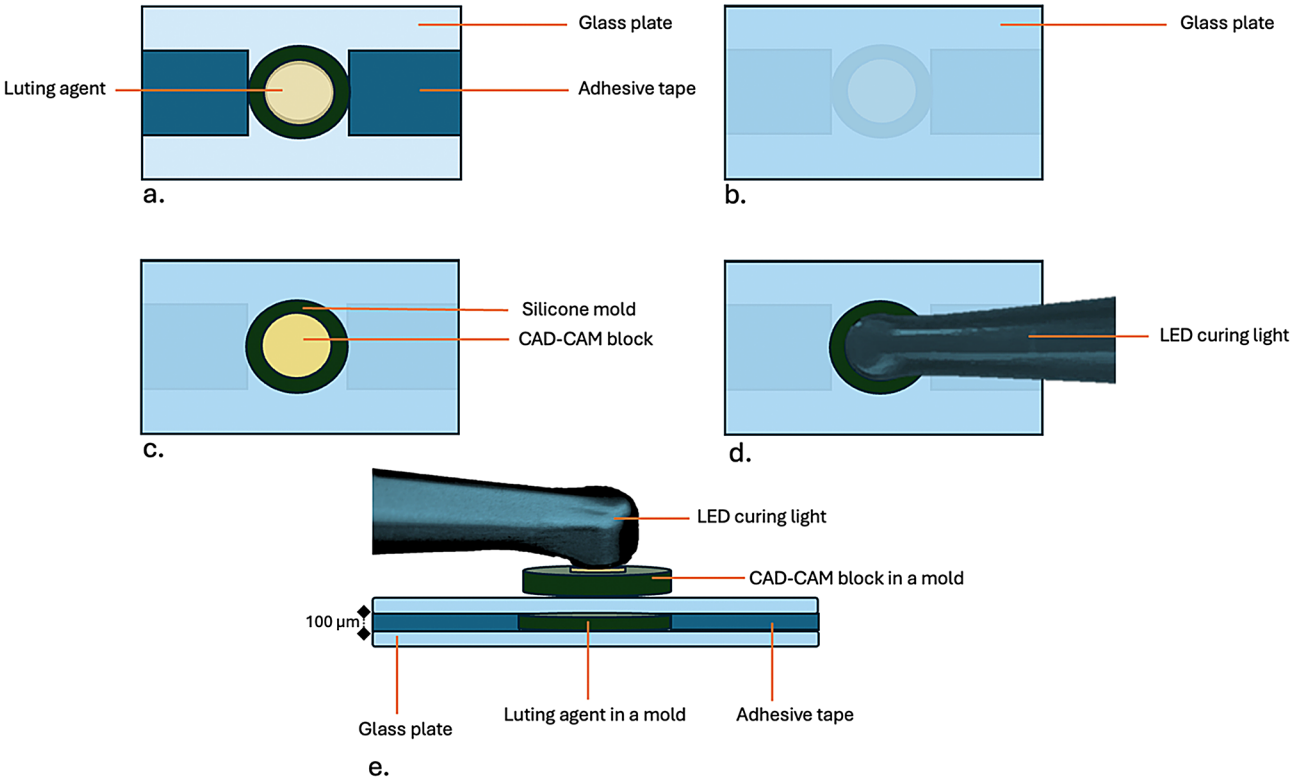


Fig. 2 **(a)** Once the Mylar strip has been positioned on the glass plate, the luting agent in the silicone mold and the adhesive tapes (100 µm thickness) were placed on it. **(b)** A Mylar strip and a glass plate were again positioned over the base configuration. **(c)** A CAD-CAM block was placed on the glass plate using a silicone mold to enclose the periphery. **(d)** Luting agents were polymerized with an LED light-curing device, allowing the light transmitted through the block to the luting agent located under the block. **(e)** Side view of the described setup

Degree of conversion (DC)

The DC of the luting material samples was calculated using Fourier Transform Infrared Spectroscopy (FTIR-4000, JASCO, Japan) with 32 scans (spectral range 400 to 4000 cm^{-1}, resolution 4 cm^{-1}). Three cured and 3 uncured samples were used for each luting material and their absorbance peaks were recorded. Using a mortar and pestle, the cured samples were ground to a fine powder. In the initial stage of the process, the spectral range was identified as a range between 1550 cm^{-1} and 1660 cm^{-1}. Following recording of the FTIR spectra, two peaks were selected for DC calculations: 1608 cm^{-1} (internal aromatic carbon double bond, C=C) and 1634 cm^{-1} (methacrylate C=C). DC (%) was calculated following the formula:

$$DC = \left(1 \frac{\left(\frac{1634\ cm^{-1}}{1608\ cm^{-1}}\right)\ \text{cured}}{\left(\frac{1634\ cm^{-1}}{1608\ cm^{-1}}\right)\ \text{uncured}}\right) \times\ 100$$

Statistical analysis

Data was analyzed using SPSS V23 (IBM, USA). The study examined compliance with normal distribution using the Shapiro-Wilk test. Non-normally distributed data was compared between binary groups using the Mann-Whitney U test, while normally distributed data was compared using the independent Two-sample t-test. Non-normally distributed data among three or more groups was compared using the Kruskal-Wallis test, and multiple comparisons were made using the Dunn Test. One-way analysis of variance was utilized to compare normally distributed data among three or more groups, and the Tukey test was used for multiple comparisons. The analysis results were presented as "mean±standard deviation" and "median (minimum-maximum)" for quantitative variables. The significance level was set at $p<0.050$.

Results

Translucency parameter, contrast ratio, and opalescence

TP_{00}, TP_{ab}, CR, and OP values were statistically significantly different regarding the thickness of blocks ($p<0.05$). TP_{00}, TP_{ab}, and OP decreased as the material thickness increased in all groups. However, CR was directly proportional to the thickness of the blocks. The CR value of the block with 2 mm thickness was higher than that of the 1.5 mm thickness (Table 2). The TP_{00}, TP_{ab}, CR, and OP values of different brands of blocks were significantly different even if they were at the same thickness ($p<0.05$) (Table 3) (Fig. 3).

Table 2 Comparison of translucency (TP_{00} and TP_{ab}), contrast ratio (CR), and opalescence (OP) according to the thickness of blocks

Parameter	CAD-CAM block	Thickness		Test statistics	*p*
		1.5 mm	2 mm		
TP_{00}	**IPS e.max CAD**	9.45 ± 0.13	8.68 ± 0.1	0.000	**0.008***
		9.36 (9.36–9.6)	8.7 (8.58–8.79)		
	Cerasmart	10.78 ± 0.18	9.29 ± 0.29	0.000	**0.008***
		10.86 (10.46–10.86)	9.09 (9.05–9.6)		
	Grandio Blocs	11.98 ± 0.46	9.39 ± 0.16	0.000	**0.008***
		11.66 (11.64–12.48)	9.44 (9.23–9.6)		
TP_{ab}	**IPS e.max CAD**	9.03 ± 0.19	7.23 ± 0.11	0.000	**0.008***
		8.89 (8.89–9.24)	7.24 (7.12–7.35)		
	Cerasmart	9.65 ± 0.3	7.1 ± 0.08	18.429	**< 0.001****
		9.75 (9.35–10.05)	7.06 (7–7.19)		
	Grandio Blocs	9.67 ± 0.19	8.64 ± 0.07	11.226	**< 0.001****
		9.71 (9.46–9.85)	8.62 (8.58–8.71)		
CR	**IPS e.max CAD**	0.67 ± 0.00	0.76 ± 0.08	0.000	**0.008***
		0.67 (0.67–0.67)	0.75 (0.70–0.88)		
	Cerasmart	0.60 ± 0.01	0.65 ± 0.01	0.000	**0.008***
		0.60 (0.59–0.61)	0.66 (0.64–0.66)		
	Grandio Blocs	0.58 ± 0.02	0.68 ± 0.01	-12.770	**< 0.001****
		0.59 (0.56–0.60)	0.68 (0.67–0.68)		
OP	**IPS e.max CAD**	9.67 ± 0.19	8.64 ± 0.07	11.226	**< 0.001****
		9.71 (9.46–9.85)	8.62 (8.58–8.71)		
	Cerasmart	9.65 ± 0.3	7.1 ± 0.08	18.429	**< 0.001****
		9.75 (9.35–10.05)	7.06 (7–7.19)		
	Grandio Blocs	9.03 ± 0.19	7.26 ± 0.34	0.000	**0.008***
		8.89 (8.89–9.24)	7.23 (6.98–7.79)		

*Mann Whitney U test, **Independent two sample t test; mean ± standard deviation, median (minimum – maximum)

Table 3 Comparison of translucency (TP_{00} and TP_{ab}), contrast ratio (CR), and opalescence (OP) of different blocks

Parameter	Thickness	CAD-CAM blocks			Test statistics	*p*
		IPS e.max CAD	Cerasmart	Grandio Blocs		
TP_{00}	**1.5 mm**	9.45 ± 0.13	10.78 ± 0.18	11.98 ± 0.46	12.64	**0.002****
		9.36 (9.36–9.6)^{b}	10.86 (10.46–10.86)^{ab}	11.66 (11.64–12.48)^{a}		
	2 mm	8.68 ± 0.1	9.29 ± 0.29	9.39 ± 0.16	9.60	**0.008****
		8.7 (8.58–8.79)^{b}	9.09 (9.05–9.6)^{a}	9.44 (9.23–9.6)^{a}		
TP_{ab}	**1.5 mm**	9.03 ± 0.19	9.65 ± 0.3	9.67 ± 0.19	9.57	**0.008****
		8.89 (8.89–9.24)^{b}	9.75 (9.35–10.05)^{a}	9.71 (9.46–9.85)^{a}		
	2 mm	7.23 ± 0.11^{b}	7.1 ± 0.08^{b}	8.64 ± 0.07^{a}	457.09	**< 0.001***
		7.24 (7.12–7.35)	7.06 (7–7.19)	8.62 (8.58–8.71)		
CR	**1.5 mm**	0.67 ± 0.00	0.60 ± 0.01	0.58 ± 0.02	11.71	**0.003****
		0.67 (0.67–0.67)^{b}	0.60 (0.59–0.61)^{ab}	0.59 (0.56–0.60)^{a}		
	2 mm	0.76 ± 0.08	0.65 ± 0.01	0.68 ± 0.01	12.61	**0.002****
		0.75 (0.70–0.88)^{b}	0.66 (0.64–0.66)^{a}	0.68 (0.67–0.68)^{ab}		
OP	**1.5 mm**	9.67 ± 0.19	9.65 ± 0.3	9.03 ± 0.19	9.57	**0.008****
		9.71 (9.46–9.85)^{a}	9.75 (9.35–10.05)^{a}	8.89 (8.89–9.24)^{b}		
	2 mm	8.64 ± 0.07^{a}	7.1 ± 0.08^{b}	7.26 ± 0.34^{b}	86.74	**< 0.001***
		8.62 (8.58–8.71)	7.06 (7–7.19)	7.23 (6.98–7.79)		

*One-way analysis of variance, **Kruskal Wallis test of variance, mean ± standard deviation, median (minimum – maximum). a-b: The same letter is not significantly different

Degree of conversion (DC)

No significant difference was detected in DC between Grandio Flow and Bifix QM under 1.5 mm blocks in all groups ($p>0.05$). A significant difference was found between the luting materials under 2 mm IPS e.max CAD. The DC of the Grandio Flow was higher than that of the Bifix QM ($p=0.011$) (Table 4). The DC of the luting materials did not differ significantly depending on the block thickness, except for Grandio Flow under Cerasmart blocks. DC of Grandio Flow under 2 mm Cerasmart was higher than that of 1.5 mm ($p=0.039$). In addition, the DC of Grandio Flow was similar when used under different blocks at the same thickness ($p=0.113$ for 1.5 mm and $p=0.064$ for 2 mm). A similar result was observed for Bifix QM ($p=0.565$ for 1.5 mm and $p=0.169$ for 2 mm) (Table 5).

Discussion

The use of CAD-CAM restorations in digital dentistry has become increasingly prevalent in recent years, particularly for indirect restorations. Currently, a range of materials such as glass ceramics, zirconia, hybrid ceramics, and resin composites can be used in CAD-CAM restorations [1, 2]. Block thicknesses in the present study were determined following the manufacturer's instructions and to mimic clinical conditions. Different tooth-preparation configurations needed to be restored by indirect restorations with various thicknesses in the clinical practice [28]. This in-vitro study was aimed to assess the optical properties (translucency, opalescence, and contrast ratio) of CAD-CAM blocks with different structures and thicknesses, and the degree of conversion of different luting materials under these blocks. Studies have demonstrated that the masking and esthetic effects might be correlated with the translucency values while the TP (translucency parameter) values of the materials varied. Although the TP values are in a similar range, the OP (opalescence parameter) can alter the masking effect. Consequently, it is necessary to confirm the quantitative role of the opalescence [29]. The phenomenon of opalescence is the result of the scattering of visible light, which gives the material a "bluish" appearance in reflected light and an "orange and brown" appearance in transmitted light. This is the reason for the higher scattering of shorter wavelengths than longer wavelengths of light [30]. In order to achieve the optimal physical or chemical properties of the polymerized luting resin cement, the thickness and translucency of ceramic restorations should also be considered, as different amounts of light are transmitted to the luting material [14, 31]. Various instruments and systems can be used to evaluate the color or translucency of restorative materials [32]. In this study, a spectrophotometer was used for translucency assessment. Spectrophotometers measure the interaction of light with a material. Light can be reflected, transmitted, scattered, or absorbed; a substance may also emit light as it absorbs and re-emits some of it.

A variety of studies have found high translucency parameters for glass ceramics and lower values for polymer-based ceramics. Additionally, resin-based composites have been found to possess higher translucency [33–35]. Consistent with this information, in this study, it was observed that lithium disilicate glass ceramic (IPS e.max CAD) showed lower translucency compared to ceramic hybrid (Cerasmart and Grandio Blocs) materials. Wang et al. claimed that the visually high crystalline

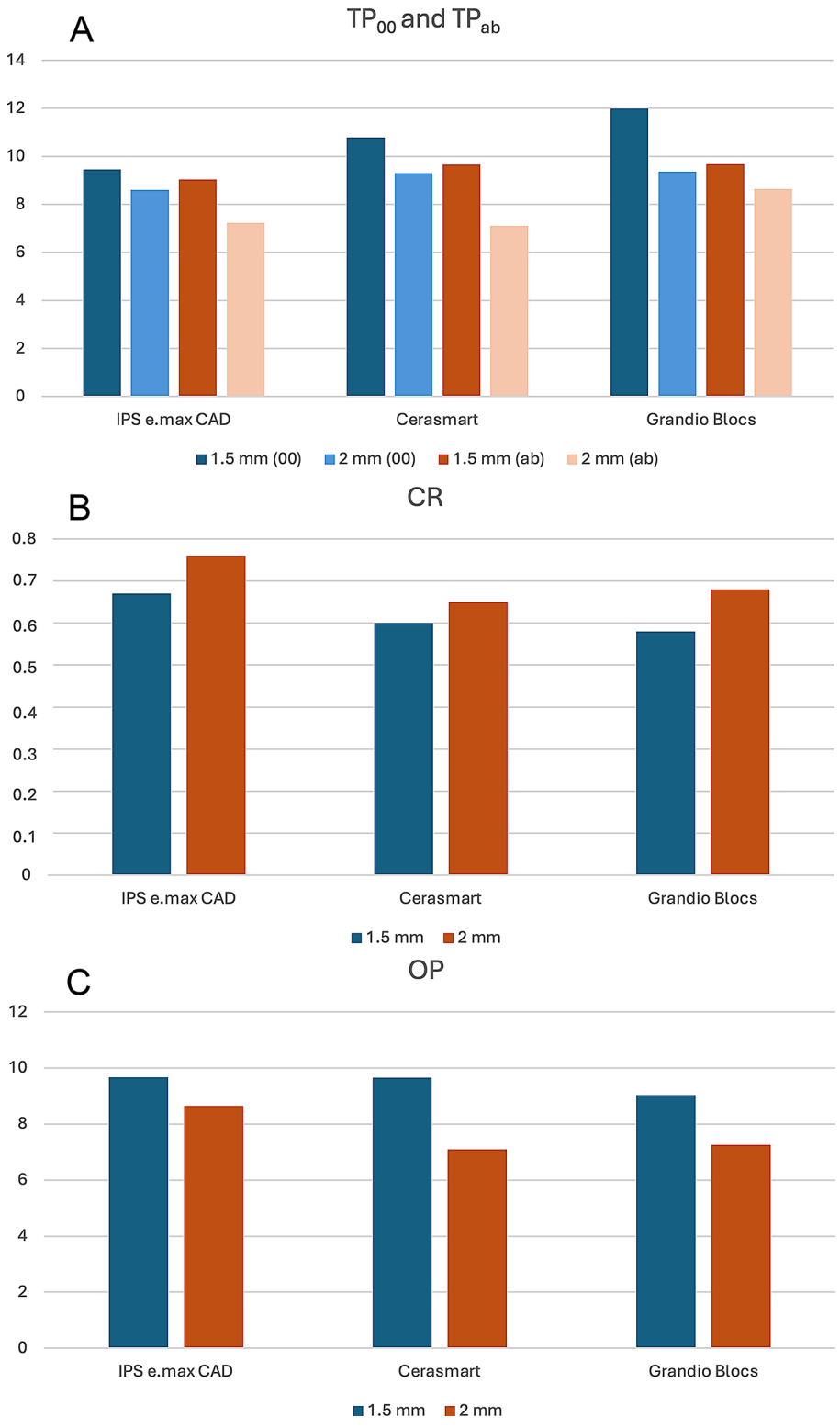


Fig. 3 **(a)** TP_{00} and TP_{ab} values of the CAD-CAM blocks. **(b)** CR values of the CAD-CAM blocks. **(c)** OP values of the CAD-CAM blocks

content, along with the arrangement of crystals along the pressing direction, might contribute to mechanical strength and higher opacity. Researchers also stated that the translucency is controlled by the nano-structure and size of the crystals in lithium disilicate glass ceramics [36]. Likewise, Della Bona et al. found that the chemical composition and microstructure, mainly the particle size, might clarify the differences in translucency

Table 4 Comparison of DC% (degree of conversion) of luting materials under the same thickness of blocks

		Luting material		Test statistics	*p*
CAD-CAM block	**Thickness**	**Bifix QM**	**Grandio Flow**		
Cerasmart	**1.5 mm**	30.8 ± 6.67	35.81 ± 2.2	-0.433	0.695*
		27.4 (26.5–38.5)	35.1 (34–38.3)		
	2 mm	30.8 ± 8.62	45.39 ± 4.82	-1.236	0.284*
		31.5 (20.3–39.8)	45.6 (40.5–50.1		
IPS e.max CAD	**1.5 mm**	23.36 ± 2.03	37.94 ± 5.33	-0.860	0.476*
		23.6 (21.2–25.2)	39.4 (32–42.4)		
	2 mm	30.8 ± 8.62	45.39 ± 4.82	-4.428	**0.011***
		31.5 (20.3–39.8)	45.6 (40.5–50.1)		
Grandio Blocs	**1.5 mm**	35.7 ± 4.77	34.94 ± 4.24	0.000	0.050**
		33 (32.9–41.2)	33.2 (31.8–39.8)		
	2 mm	30.8 ± 8.62	45.39 ± 4.82	4.000	0.827**
		31.5 (20.3–39.8)	45.6 (40.5–50.1)		

*Mann Whitney U test, **Independent two sample t test; mean ± standard deviation, median (minimum – maximum)

Table 5 Comparison of DC% (degree of conversion) according to different blocks and different thicknesses

		Thickness			Test statistics	*p*
Luting material	**CAD-CAM block**	**Direct**	**1.5 mm**	**2 mm**		
Bifix QM	CeraSmart	33.71 ± 8.43	30.8 ± 6.67	30.8 ± 8.62	0.137	0.874*
		36.9 (24.2–40.1)	27.4 (26.5–38.5)	31.5 (20.3–39.8)		
	IPS e.max CAD	34.68 ± 13.21	23.36 ± 2.03	30.8 ± 8.62	1.986	0.267*
		41.5 (19.4–43.1)	23.6 (21.2–25.2)	31.5 (20.3–39.8)		
	Grandio Blocs	24.94 ± 1.93	35.7 ± 4.77	30.8 ± 8.62	3.609	0.165**
		24.1 (23.6–27.1)	33 (32.9–41.2)	31.5 (20.3–39.8)		
Test Statistics			0.720	5.033		
p			0.565*	0.169**		
Grandio Flow	CeraSmart	36.07 ± 4.22	35.81 ± 2.2	45.39 ± 4.82	5.838	**0.039***
		36.7 (31.6–39.9)	35.1 (34–38.3)	45.6 (40.5–50.1)		
	IPS e.max CAD	41.33 ± 2.28	37.94 ± 5.33	45.39 ± 4.82	2.204	0.192*
		42.4 (38.7–42.8)	39.4 (32–42.4)	45.6 (40.5–50.1)		
	Grandio Blocs	38.07 ± 4.57	34.94 ± 4.24	45.39 ± 4.82	4.356	0.113**
		40.7 (32.8–40.7)	33.2 (31.8–39.8)	45.6 (40.5–50.1)		
Test Statistics			5.974	3,637		
p			0.113**	0.064*		

*One-way analysis of variance, **Kruskal Wallis test, mean ± standard deviation, median (minimum-maximum)

parameter values [10]. Moreover, it has been reported that the same translucency levels (high translucent, low translucent) do not have any correlation among different manufacturers [37]. In this study, the TP values of low translucent blocks with the same thickness were as follows: Grandio Blocs > Cerasmart > IPS e.max CAD. Contrary to the findings of the current study, a previous study revealed that TP parameters were in the following order: Cerasmart > Grandio Blocs = Vita Mark II > Vita Enamic [38]. Utilizing different color measurement standards or instruments, diverse materials under investigation, and variations in value ranges across studies may lead to discrepancies [5, 6]. In this study, it was observed that as the thickness of the material increased, the translucency parameters (TP_{ab}, TP_{00}) decreased. In addition, a strong correlation was observed between TP and CR, with a decrease in TP and an increase in CR. These findings are consistent with those of previous research [10, 36, 37, 39]. Based on the results, the first hypothesis of the present study was rejected. It was also found that the TP and OP values exhibited similar behavior as the thickness changed. It is known that an optimal dental restoration should have opalescence equal to the adjacent teeth [40]. According to different studies, the opalescence value of the materials used in this study was found to be lower than that of dentin and enamel [41, 42]. In the planning of indirect restorations, it is beneficial to consider the parameters that change as the materials' thickness increases to achieve color matching and the desired appearance effects.

Furthermore, this study also examined the degree of conversion (DC) of two different light- and dual-cured luting materials containing Bis-GMA (bisphenol-A glycidyl-dimethacrylate). Many analytical methodologies

have been developed for DC analysis in organic matrices of Bis-GMA-based resin materials. Among these, Fourier transform infrared spectroscopy (FTIR) is the most frequently used methodology and it was preferred in this study to analyze 100 μm thick samples. In terms of polymerization, there are 3 types of resin matrix: self-curing, dual-curing, and light-curing. Dual-cured resin cement combines the desirable characteristics of chemically- and light-cured resin cement [16]. In addition to the advantage of further chemical curing in deeper areas where penetration of light is reduced, dual-cured resin cements have demonstrated enhanced mechanical properties compared to isolated light activation or only chemical curing [43]. Resin cements from different manufacturers may also differ in the DC under the CAD-CAM blocks. Lopes et al. showed that DC was affected only by the type of resin cement [44]. Moreover, resin cement has a similar composition as resin composites, and light-cured flowable resin composites are also used in cementation because they provide benefits comparable to cement due to their physical properties [23, 25, 45]. Liberato et al. reported that resin composites might produce lower polymerization stress than resin cement when luting veneers and the level of polymerization stress was found to be dependent on the shrinkage, but not on the DC or the elastic modulus [46]. Resin-based systems are activated physically. It is known that the light irradiance emitted by a light curing unit, which reaches the cement, is reduced when it passes through the ceramic, resulting in a reduction in the degree of conversion [47]. The results of this study mostly showed no difference in DC of dual-cured and light-cured luting materials under different CAD-CAM blocks with the same thickness. The only difference was observed between the DC of Grandio Flow light-cured flowable resin composite and Bifix QM dual-cured resin cement under 2 mm lithium disilicate glass ceramic block (IPS e.max CAD). The DC of Grandio Flow was significantly higher than Bifix QM. Therefore, the second hypothesis of the present study was partially accepted. Although there has been no consensus on the minimum clinically acceptable DC, it can be observed that commercial resin composite structures exhibit a DC of between 50% and 75% following polymerization. In this study, the DC of both luting materials was below 50% even if they were directly polymerized in the control group. However, autopolymerization was reported to be completed in approximately two weeks, particularly for dual-cured resin materials [48]. Similarly, Shim et al. also found that cement had relatively high DC after 2 weeks under different restorative materials and using different light-curing methods [49]. Likewise, an increase in the DC of light-cured resin composites over time has been observed in a previous study [50]. This is the probable reason for there was no difference between dual and light-cured luting materials under ceramic hybrid materials in the early stages (after 24 h). Likewise, the fact that the light-cured material has a significantly higher DC than the dual-cured material under 2 mm glass ceramic material in the early stages can attributed to the incomplete polymerization process. On the other hand, some studies reported that, when comparing the DC of different materials, the initial DC level achieved from exposure to the polymerization device is a crucial factor in the final polymerization of dual- or light-cured resin materials [51]. It is known that all ceramic materials have different compositions, microstructures, crystalline contents, and phases, which can affect their optical properties. Increasing the crystalline content is essential for achieving higher strength, although it may lead to increased opacity [52]. The discrepancy in the DC of luting materials under 2 mm lithium disilicate glass ceramic might also be attributed to these factors even if no differences were observed under ceramic hybrid materials.

The use of a darker or more opaque shade and thicker restorative material leads to reduced light transmission through the restoration. This may affect both the adhesion to the tooth structure and the mechanical properties of the luting materials [53, 54]. Apart from this study, De Freitas et al. found that the ceramic with greater translucency showed the highest DC in all types of cement. However, the researchers investigated the effect of the thickness of the material on the DC of resin-based materials during light curing and suggested that it does not change when cured using an adequate irradiance and wavelength [14]. Similarly, no differences were found in the DC of the luting materials as the thickness of the CAD-CAM blocks was increased except light-cured Grandio Flow under 1.5 and 2 mm thick Cerasmart. According to the results, the last hypothesis of this study that "the DC of luting materials was not affected by the thickness of the blocks" was partially accepted. A previous study reported that as the thickness of the CAD-CAM block increased, the radiant power and spectral radiant power of the transmitted light from light-curing units exhibited an exponential decrease [26]. In addition, Li et al. conducted a study to examine the depth of cure of light-cured resin cement under 4 different glass ceramic blocks. The study also evaluated the minimum irradiance and radiant exposure necessary to trigger adequate polymerization. The researchers concluded that radiant exposure and irradiance to trigger adequate polymerization of light-cured resin cement of 100 μm thickness were 6 J/cm^2 and 100 mW/cm^2, respectively [55]. In this study, an LED light-curing device with an irradiance of 1000 mW/cm^2 for 20 s was utilized for polymerization of 100 μm thick resin-based luting materials. In this study, it can be considered that even when the block thickness was increased, the irradiation and minimum radiant

exposure required for adequate polymerization of the luting materials were achieved. Lise et al. also found that light-cured materials can be cured through a restoration up to 2.7 mm thickness, depending on the kind of CAD-CAM material [28]. In this study, the blocks were prepared with a maximum thickness of 2 mm and the results correlate with the conclusions of the mentioned study. The DC of these materials remained generally unaffected by the thickness of the blocks after the early stage (24 h). However, one notable exception was observed: the light-cured luting material Grandio Flow exhibited a higher DC under the thicker block, contrary to the expected result. This result was observed for the Cerasmart CAD-CAM block. This result might be attributed to several conditions. When the optimal conditions for irradiation and minimum radiant exposure are provided for adequate polymerization, the chain propagation process, initiated by the photoinitiator, will continue until all monomers have converted to a polymer network for each sample [56]. Although 24 h post-irradiation measurements are sufficient to determine polymer matrix formation, polymerization may continue for more than seven days for light-cured resin composites [57]. Later stages of polymerization were not evaluated in this study. The present study demonstrated no significant difference in polymerization between dual-cured resin cement and flowable resin composite. Consequently, it can be stated that flowable composites are a viable alternative for cementation in the clinical setting when considering this study. Furthermore, the DC analysis methods may be influenced by factors such as sample preparation, storage, and the analysis method used. A previous study has demonstrated that the results obtained through different analysis methods may vary [58]. In DC studies, incorporating diverse analysis methods can facilitate a comprehensive evaluation of the results. It is important to consider that for cementation procedures in the clinical conditions, even if there was no difference in the DC with increasing restoration thickness in this study, or even if it increased under 2 mm thick Cerasmart for Grandio Flow, other studies have reported that radiant power decreases with increasing thickness [26]. Once the requisite level of transmitted radiant power or irradiance has been reached, the polymerization process can be initiated and completed [55]. Therefore, one of the limitations was that the irradiance and radiant exposure transmitted from the blocks were not included in this study. In a further study, the researchers found differences in the DC of dual-cured and light-cured luting materials, depending on the blocks and LED curing unit used in different modes [59]. The present study was also limited in not including different LED curing devices or curing modes. In addition, the color measurement differences between various devices, the variety of CAD-CAM blocks and dual- and light-cured resin-based materials, and the early-stage evaluation of the DC of luting materials represent the limitations of this study. Consequently, future studies should investigate the optical properties of different materials and their structures and compositions, while also considering the later-stage degree of conversion of different luting materials such as various cements or flowable resin composites. It is known that the lifespan of the materials depends on several factors. It would therefore be beneficial to include a variety of properties and to conduct studies with clinical follow-up.

Conclusion

Within the limitations of this study,

In addition to the structure and curing mechanism of the resin-based cement or composite, the structure, thickness, and optical properties of the CAD-CAM blocks affect the polymerization of the luting material. However, while translucency, opalescence, and contrast ratio varied depending on block thickness (1.5 and 2 mm), the degree of conversion of luting materials under the block remained generally identical. This study found no difference between flowable resin composite and dual-cured resin cement in terms of polymerization except for luting materials under 2 mm thick lithium disilicate glass ceramic CAD-CAM block. It is known that the mechanical, chemical, and physical properties of the luting material affect the lifespan of the restoration, so it would be beneficial for further research to include a wider variety of materials and methods for both CAD-CAM blocks and luting materials such as different flowable resin composites.

Author contributions

Conceptualization B.D.K., S.Ö., A.A.Ş., E.K., P.Y.A., and B.T.; methodology, B.D.K., E.K., P.Y.A. and B.T.; software, B.D.K.; formal analysis, B.D.K., A.A.Ş., E.K., P.Y.A., and B.T.; investigation, B.D.K. and S.Ö.; data curation, B.D.K., S.Ö., and A.A.Ş.; writing—original draft preparation, B.D.K. and S.Ö.; writing—review and editing, B.D.K., A.A.Ş., E.K., P.Y.A., and B.T.; supervision, A.A.Ş., E.K., P.Y.A., and B.T.; funding acquisition, P.Y.A., E.K., and B.T.; administration, B.D.K., S.Ö., and A.A.Ş. All authors have read and agreed to the published version of the manuscript.

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Data availability

The data that support the findings of this study are available on request from the corresponding author.

Declarations

Ethical approval

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Consent for publication

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Competing interests

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References

1. Skorulska A, Piszko P, Rybak Z, Szymonowicz M, Dobrzyński M. Review on polymer, ceramic and composite materials for cad/cam indirect restorations in dentistry—Application, mechanical characteristics and comparison. Materials. 2021;14(7):1592.
2. Sulaiman TA. Materials in digital dentistry—A review. J Esthetic Restor Dentistry. 2020;32(2):171–81.
3. Silami FDJ, Tonani R, Alandia-Román CC, Pires-de-Souza FCP. Influence of different types of resin luting agents on color stability of ceramic laminate veneers subjected to accelerated artificial aging. Braz Dent J. 2016;27:95–100.
4. Alqahtani MQ, Aljurais RM, Alshaafi MM. The effects of different shades of resin luting cement on the color of ceramic veneers. Dent Mater J. 2012;31(3):354–61.
5. Vichi A, Zhao Z, Paolone G, Scotti N, Mutahar M, Goracci C, et al. Factory crystallized silicates for monolithic metal-free restorations: a flexural strength and translucency comparison test. Materials. 2022;15(21):7834.
6. Tolba ZO, Hassanien EEY. Translucency and colour masking ability of hybrid CAD/CAM materials with different thicknesses: in vitro study. BDJ open. 2024;10(1):63.
7. Shirani M, Savabi O, Mosharraf R, Akhavankhaleghi M, Hebibkhodaei M, Isler S. Comparison of translucency and opalescence among different dental monolithic ceramics. J Prosthet Dent. 2021;126(3):446. e1-. e6.
8. Salas M, Lucena C, Herrera LJ, Yebra A, Della Bona A, Pérez MM. Translucency thresholds for dental materials. Dent Mater. 2018;34(8):1168–74.
9. Gunal B, Ulusoy MM. Optical properties of contemporary monolithic CAD-CAM restorative materials at different thicknesses. J Esthetic Restor Dentistry. 2018;30(5):434–41.
10. Della Bona A. Bonding to ceramics: scientific evidences for clinical dentistry. Artes Médicas; 2009.
11. Ruiz-López J, Espinar C, Lucena C, de la Cruz Cardona J, Pulgar R, Pérez MM. Effect of thickness on color and translucency of a multi-color polymer-infiltrated ceramic-network material. J Esthetic Restor Dentistry. 2023;35(2):381–9.
12. Schweiger J, Güth J-F, Schubert O, Sciuk T, Beuer F, Erdelt K-J. Predictable esthetics in all-ceramic restorations: translucency as a function of material thickness. Int J Comput Dent. 2021;24(2).
13. Johnston WM. Review of translucency determinations and applications to dental materials. J Esthetic Restor Dentistry. 2014;26(4):217–23.
14. de Freitas M-R, Zanatta R-F, Catelan A. Influence of thickness and translucency of lithium disilicate ceramic on degree of conversion of resinous materials. J Clin Experimental Dentistry. 2020;12(8):e745.
15. Meng X, Yoshida K, Atsuta M. Influence of ceramic thickness on mechanical properties and polymer structure of dual-cured resin luting agents. Dent Mater. 2008;24(5):594–9.
16. Prieto LT, de Araújo CTP, Pierote JJA, de Oliveira DCRS, Coppini EK, Paulillo LAMS. Evaluation of degree of conversion and the effect of thermal aging on the color stability of resin cements and flowable composite. J Conservative Dentistry Endodontics. 2018;21(1):47–51.
17. Watanabe H, Kazama R, Asai T, Kanaya F, Ishizaki H, Fukushima M, et al. Efficiency of dual-cured resin cement polymerization induced by high-intensity LED curing units through ceramic material. Oper Dent. 2015;40(2):153–62.
18. Supornpun N, Oster M, Phasuk K, Chu T-MG. Effects of shade and thickness on the translucency parameter of anatomic-contour zirconia, transmitted light intensity, and degree of conversion of the resin cement. J Prosthet Dent. 2023;129(1):213–9.
19. Manso AP, Carvalho RM. Dental cements for luting and bonding restorations: self-adhesive resin cements. Dent Clin. 2017;61(4):821–34.
20. Saker S. Clinical and radiographic assessment of reasons for replacement of metal-ceramic fixed dental prostheses in patients referring to dental school. J Clin Experimental Dentistry. 2018;10(1):e75.
21. Kelch M, Stawarczyk B, Mayinger F. Time-dependent degree of conversion, Martens parameters, and flexural strength of different dual-polymerizing resin composite luting materials. Clin Oral Invest. 2022;26(1):1067–76.
22. Archegas LRP, de Menezes Caldas DB, Rached R, Soares P, Souza E. Effect of ceramic veneer opacity and exposure time on the polymerization efficiency of resin cements. Oper Dent. 2012;37(3):281–9.
23. Archegas LRP, Freire A, Vieira S, de Menezes Caldas DB, Souza EM. Colour stability and opacity of resin cements and flowable composites for ceramic veneer luting after accelerated ageing. J Dent. 2011;39(11):804–10.
24. Kameyama A, Bonroy K, Elsen C, LŘhrs A-K, Suyama Y, Peumans M, et al. Luting of CAD/CAM ceramic inlays: direct composite versus dual-cure luting cement. Biomed Mater Eng. 2015;25(3):279–88.
25. Tomaselli LO, Oliveira DCRSd, Favarão J, Silva AFd, Pires-de-Souza FCP, Geraldeli S, et al. Influence of pre-heating regular resin composites and flowable composites on luting ceramic veneers with different thicknesses. Braz Dent J. 2019;30:459–66.
26. Mazao JD, Ribeiro MTH, Braga SSL, Zancope K, Price RB, Soares CJ. Effect of thickness and shade of CAD/CAM composite on the light transmission from different light-curing units. Brazilian Oral Res. 2023;37:e114.
27. Monterubbianesi R, Vitiello F, Tosco V, Bourgi R, Putignano A, Orsini G. The influence of two curing protocols on the colour stability and translucency of resin luting agents. Appl Sci. 2022;12(21):11120.
28. Lise DP, Van Ende A, De Munck J, Yoshihara K, Nagaoka N, Vieira LCC, et al. Light irradiance through novel CAD–CAM block materials and degree of conversion of composite cements. Dent Mater. 2018;34(2):296–305.
29. Daneshpooy M, Azar FP, Oskoee PA, Bahari M, Asdagh S, Khosravani SR. Color agreement between try-in paste and resin cement: effect of thickness and regions of ultra-translucent multilayered zirconia veneers. J Dent Res Dent Clin Dent Prospects. 2019;13(1):61.
30. Rafael CF, Del Pina Luna M, Munõz MT, Garbelotto DA, Gustavo L, Liebermann A et al. Optical factors: affecting Anterior esthetics in all-ceramic restorations: two case reports. J Cosmet Dentistry. 2017;33(3).
31. Chen T-A, Lu P-Y, Lin P-Y, Chi C-W, Cheng HY, Lai Y-J, et al. Effects of ceramic thickness, ceramic translucency, and light transmission on light-cured bulk-fill resin composites as luting cement of lithium disilicate based-ceramics. J Prosthodontic Res. 2023;68(2):255–63.
32. Sasany R, Yilmaz B. Effect of stain brand and shade on color stability of stains applied on a CAD-CAM feldspathic ceramic. Odontology. 2022;110(3):452–9.
33. Su Y, Xin M, Chen X, Xing W. Effect of CAD-CAM ceramic materials on the color match of veneer restorations. J Prosthet Dent. 2021;126(2):255. e1-. e7.
34. Horvath SD. Key parameters of hybrid materials for CAD/CAM-Based restorative Dentistry. Compendium Continuing Educ Dentistry (Jamesburg NJ: 1995). 2016;37(9):638–43.
35. Porojan L, Vasiliu RD, Porojan SD. Masking abilities of dental cad/cam resin composite materials related to substrate and luting material. Polymers. 2022;14(3):364.
36. Wang F, Yu T, Chen J. Biaxial flexural strength and translucent characteristics of dental lithium disilicate glass ceramics with different translucencies. J Prosthodontic Res. 2019;64(1):71–7.
37. Vichi A, Balestra D, Scotti N, Louca C, Paolone G. Translucency of CAD/CAM and 3D printable composite materials for permanent dental restorations. Polymers. 2023;15(6):1443.
38. Babaier R, Silikas N, Watts D. Effect of CAD/CAM thickness and translucency on the polymerisation of Resin cements. Dent Mater. 2023;39:e10–1.
39. Wu Z, Tian J, Wei D, Zhang Y, Lin Y, Di P. Effects of thickness and polishing treatment on the translucency and opalescence of six dental CAD-CAM monolithic restorative materials: an in vitro study. BMC Oral Health. 2023;23(1):579.
40. Juntavee N, Attashu S. Effect of sintering process on color parameters of nano-sized yttria partially stabilized tetragonal monolithic zirconia. J Clin Experimental Dentistry. 2018;10(8):e794.
41. Lee Y-K, Yu B. Measurement of opalescence of tooth enamel. J Dent. 2007;35(8):690–4.
42. Lee Y-K. Opalescence of human teeth and dental esthetic restorative materials. Dent Mater J. 2016;35(6):845–54.
43. Park S-H, Kim S-S, Cho Y-S, Lee C-K, Noh B-D. Curing units' ability to cure restorative composites and dual-cured composite cements under composite overlay. Oper Dent. 2004;29(6):627–35.
44. Lopes CCA, Rodrigues RB, Simamoto Júnior PC, Soares CJ, Novais VR. Degree of conversion and mechanical properties of resin cements cured through different all-ceramic systems. Braz Dent J. 2015;26:484–9.
45. Lassila L, Garoushi S, Mangoush E, Vallittu PK, Säilynoja E. Assessing the efficacy of Novel Fiber-Reinforced Dual-Cure Luting Resins. J Clin Experimental Dentistry. 2024;16(3):e333.
46. Liberato WF, Silikas N, Watts DC, Cavalcante LM, Schneider LFJ. Luting laminate veneers: do resin-composites produce less polymerization stress than resin cements? Dent Mater. 2023;39(12):1190–201.

47. Standardization IOf. Dentistry: Guidance on Colour Measurement. International Organization for Standardization; 2011.
48. Bayne SC. Dental biomaterials: where are we and where are we going? J Dent Educ. 2005;69(5):571–85.
49. Shim JS, Kang JK, Jha N, Ryu JJ. Polymerization mode of self-adhesive, dual-cured dental resin cements light cured through various restorative materials. J Esthetic Restor Dentistry. 2017;29(3):209–14.
50. Ghavami-Lahiji M, Firouzmanesh M, Bagheri H, Kashi TSJ, Razazpour F, Behroozibakhsh M. The effect of thermocycling on the degree of conversion and mechanical properties of a microhybrid dental resin composite. Restor Dentistry Endodontics. 2018;43(2).
51. Gajewski VE, Pfeifer CS, Fróes-Salgado NR, Boaro LC, Braga RR. Monomers used in resin composites: degree of conversion, mechanical properties and water sorption/solubility. Braz Dent J. 2012;23:508–14.
52. Sakaguchi RL, Powers JM. Craig's Restorative. Dental Materials. 2012:161 – 98.
53. Borges LPS, Borges GA, Correr AB, Platt JA, Kina S, Correr-Sobrinho L, et al. Effect of lithium disilicate ceramic thickness, shade and translucency on transmitted irradiance and knoop microhardness of a light cured luting resin cement. J Mater Science: Mater Med. 2021;32:1–9.
54. de Araújo Neto VG, Soto-Montero J, de Castro EF, Feitosa VP, Rueggeberg FA, Giannini M. Effects of shades of a multilayered zirconia on light transmission, monomer conversion, and bond strength of resin cement. J Esthetic Restor Dentistry. 2022;34(2):412–22.
55. Li Q, Lin H-L, Zheng M, Ozcan M, Yu H. Minimum radiant exposure and irradiance for triggering adequate polymerization of a photo-polymerized resin cement. Materials. 2021;14(9):2341.
56. Mayinger F, Reymus M, Liebermann A, Richter M, Kubryk P, Großekappenberg H, et al. Impact of polymerization and storage on the degree of conversion and mechanical properties of veneering resin composites. Dent Mater J. 2021;40(2):487–97.
57. Par M, Lapas-Barisic M, Gamulin O, Panduric V, Spanovic N, Tarle Z. Long term degree of conversion of two bulk-fill composites. Acta Stomatol Croatica. 2016;50(4):292.
58. Bolaños-Carmona V, Benavides-Reyes C, González-López S, González-Rodríguez P, Álvarez-Lloret P. Influence of spectroscopic techniques on the estimation of the degree of Conversion of bulk-fill composites. Oper Dent. 2020;45(1):92–103.
59. Çetindemir AB, Şermet B, Öngül D. The effect of light sources and CAD/CAM monolithic blocks on degree of conversion of cement. J Adv Prosthodont. 2018;10(4):291–9.

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