Dental Materials Journal 2023; 42(1): 30–41

Effect of thickness on the translucency of resin-based composites and glass-ceramics

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This study was aimed to evaluate the effect of thickness (1, 2, 3, and 4 mm) on the translucency of resin-based composites (RBCs) and glass-ceramics, and compare the influence of the thickness of those materials on the translucency parameter (TP) value. The materials were divided into two groups, eight RBCs in Group 1 and five glass-ceramics in Group 2 and TP, ΔL^*, Δa^*, and Δb^* were compared. Statistically significant differences were present in the 2, 3, and 4 mm in the TP, in the 2 and 4 mm in ΔL^*, and in all thicknesses in Δa^* and Δb^* betweent the two groups. The TP of RBCs and glass-ceramics decreased as thickness increased, especially from 1 mm to 2 mm. The TP values of the RBCs were more significantly decreased as the thickness of the material increased from 2 mm to 4 mm than those of the glass-ceramics.

Keywords: Resin-based composites, Glass-ceramics, Translucency, Restoration thickness, Operative dentistry

INTRODUCTION

Resin composites and dental ceramics are used as major dental restorative materials worldwide. Glass-ceramics are now available in the form of monolithic ceramic blocks with advances in computer-aided design and computer-aided manufacturing (CAD/CAM) technology and have gained popularity for restoring anterior and posterior teeth as single crowns, laminates, inlays, and onlays. Many studies found that restoration with resin composites and dental ceramics exhibited a high survival rate for years and was considered a reliable treatment option for both anterior and posterior teeth[1-7]. Dental restorative materials have been developed to improve not only function and mechanics but also esthetics because of the patients' growing esthetic demands[8]. Resin-based composites (RBCs) and dental ceramic manufacturers have been trying to improve their optical properties to replicate human teeth' natural properties, and recently developed RBCs and dental ceramics that demonstrated translucency similar to that of natural teeth[9]. Esthetics are important because restoring natural teeth is one of the goals of clinicians[10]. However, information on the esthetics of dental materials to mimic natural teeth is still insufficient.

Translucency in esthetic restorative materials influences color harmonization with the surrounding or adjacent teeth and restorations[11]. There are three kinds of translucency indicators commonly used in the field of esthetic prosthodontics, transmittance (T), the contrast ratio (CR), and the translucency parameter (TP)[12]. Among these three indicators, the TP value is generally considered to be more applicable to the visual evaluation of translucency[13,14], and is calculated as the color difference from a white and black background[14] in a uniform thickness of a substance. Higher TP values of a material correlate with higher translucency, whereas lower TP values correspond to materials with lower translucency. TP values can range from 0 (totally opaque material) to 100 (totally transparent material)[15].

The translucency of intracoronal restorative materials also affects clinical performance especially in ceramic restoration by influencing the physicochemical properties of adhesive cementation underlying the materials. During cementation in indirect restoration, the light-curing unit's irradiance at the luting agent is impaired as ceramic restorations are more opaque and thicker, which may reduce the physicochemical properties of these materials[16-18]. Reductions in translucency by increasing resin composites' thickness and dental ceramics have been reported[19-27]. To the best of our knowledge, most of them have studied the translucency of materials with thicknesses up to 2 mm, and little information has been reported on materials with thicker dimensions even though coronal restoration thicknesses can extend to more than 2 mm. Besides, those studies investigated the effect of the thickness and translucency of RBCs[19,24,25] and dental ceramics[20-23,26,27] separately even though the two materials have the same indications for use in many clinical situations. Certain cases encountered in clinical practice can be indications for both ceramic and composite resins, such as restoring fractured anterior teeth[7,28], facing, and masking discolored teeth[29] and deep proximal caries, where the restoration thickness would be more than 2 mm. In these cases, we need to simultaneously evaluate the physical, chemical, adhesive, and esthetic characteristics of the two materials and choose one. Therefore, evaluation on translucency of restoration thickness more than 2 mm could also be necessary for material choice regarding the clinical situation.

This study aimed to evaluate the effect of thickness (1, 2, 3, and 4 mm) on the translucency of RBCs and glass-ceramics using a colorimeter and compare the influence

Received Apr 19, 2022: Accepted Jul 12, 2022
doi:10.4012/dmj.2022-093 JOI JST.JSTAGE/dmj/2022-093

of the thickness of those two materials on the TP value. The hypothesis were that (1) material thickness would affect the TP of RBCs and glass-ceramics, and (2) there is no significant change in translucency between RBCs and glass-ceramics at a certain thickness.

MATERIALS AND METHODS

RBC and glass-ceramic materials

Seven different A3 shade RBC products (Beautifil II [BF], Estelite Sigma Quick [ES], Filtek Z250 [F2], Filtek Z350 XT [F3], Gradia Direct [GD], Herculite Precis [HC], and Tetric N-Ceram [TC]) and one A3 shade resin nano ceramic block (Lava™ Ultimate [LU]) were selected for RBCs and are shown in Table 1. For the glass-ceramics, five different ceramic blocks in the A3 shade (Celtra® Duo [CD], Heat-cured Celtra® Duo [CDc], IPS e.max CAD HT [EMHT], IPS e.max CAD LT [EMLT], and Rainbow™ LS [RL]) were used in the experiment and are also shown in Table 1.

Specimen preparation

1. RBC preparation

Forty disk-shaped specimens including four different thickness (1, 2, 3, and 4 mm) were prepared for each of seven RBC products (BF, ES, F2, F3 GD, HC, and TC), for a total of 280 specimens (7 materials×10 specimens×4 thicknesses). A stainless-steel mold (6 mm in diameter) was placed on a transparent film on a glass slide. All specimens were obtained by placing a small amount of resin composite into the mold and pressing the resin between two glass slides to a thickness of 1, 2, 3, or 4 mm. Then, the mold and the glass slide were removed, and 1 and 2 mm thickness RBC samples were cured for 20 s, and 3 and 4 mm thickness RBC samples were cured for 40 s (20 s×2 times) using a light-curing unit (Elipar DeepCure-S, 3M ESPE, Neuss, Germany) placed directly on the surface of the material. A spectral radiometer (USB4000, Ocean Optics, Largo, FL, USA) and an integration sphere (Labsphere, North Sutton, NH, USA) were used to measure radiant exitance. When the radiant flux of the light-curing unit was measured between 350 and 600 nm, it was found to be 0.73 W (average of five measurements), which was equivalent to 1,147mW/cm^2 radiant exitance in the normal condition. After polymerization, the specimen was removed, each specimen was polished up to 4000 grit silicon-carbide (SiC) paper, and a caliper (500-181, Mitutoyo, Kanagawa, Japan) was used to measure the thickness with a precision of 0.05 mm and stored in the dark at room temperature. Specimens with defects or irregularities were rejected.

2. Glass-ceramic and resin nano ceramic block preparation

Forty specimens including four different thickness (1, 2, 3, and 4 mm) were prepared for each of five glass-ceramic blocks (CD, CDc, EMHT, EMLT, and RL) and a resin nano ceramic block (LU), for a total of 240 specimens (6 materials×10 specimens×4 thicknesses). CDc, EMHT, EMLT, and RL were fired according to the manufacturer's instruction (Programat® p300, Ivoclar Vivadent, Schaan, Liechtenstein). The glass-ceramic and resin nano ceramic blocks were cut with a low-speed water-cooled saw (DAIMO-100S, MTDI, Daejeon, South Korea) to obtain specimens with four different thickness (1, 2, 3, and 4 mm). After cutting the glass-ceramic and nano ceramic blocks, the specimens were polished with 600, 1000, 2000, and 4000 grit SiC papers, and they were measured with a caliper (500-181, Mitutoyo) with a precision of 0.05 mm. The specimens were prepared without glazing. Specimens with any defects on the surface were removed.

Evaluation of CIE L, a*, and b* values*

The color measured both on the black and white backing was coordinated with the Commission Internationale de l'Eclairage CIELAB color scale[30]. In this study, the CIE L^*, a^*, and b^* values of seven RBCs and six glass-ceramics with four different thicknesses were measured on the white and black backgrounds using a colorimeter (CR-321, Minolta, Osaka, Japan), where L^* indicates lightness (0 to 100), and a^* and b^* indicate the levels of red ($+a^*$), green ($-a^*$), yellow ($+b^*$), and blue ($-b^*$) (−60 to 60). The colorimeter was calibrated before making the measurements, and the measurements were performed by one evaluator (S.Y.R.) using the CIE standard illuminant D65. Each measurement was carried out on black and white reflectance standards (Spectralon, Labsphere). The L^*, a^*, and b^* values of the black and white backings employed in this study were $L^*=21.05$, $a^*=0.15$, and $b^*=-0.02$ for the black background, and $L^*=93.74$, $a^*=-0.07$, $b^*=1.35$ for the white background. The aperture diameter of the colorimeter was 4 mm, and each specimen was measured twice.

Translucency measurements

The TP of each specimen was calculated by the color difference of the specimen against the black and white standards according to the following formula:

$$TP=[(L_B^*-L_W^*)^2+(a_B^*-a_W^*)^2+(b_B^*-b_W^*)^2]^{1/2}$$
$$=[(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}$$

where the subscript B refers to the color coordinates of the specimens using the black background and the subscript W refers to the measurements using the white background, and where ΔL^*, Δa^*, and Δb^* are the differences between L^*, a^*, and b^* for the two backings.

Statistical analysis

The TP was compared between the different thicknesses for each RBC product and each glass-ceramic block using a one-way analysis of variance followed by Tukey's *post-hoc* test after checking normality using the Shapiro-Wilk test. TPs were also compared between the different RBCs and glass-ceramic blocks with the same thickness using a one-way analysis of variance followed by Tukey's *post-hoc* test. The materials were divided into two groups, eight RBCs (BF, ES, F2, F3, GD, HC, LU, and TC) in Group 1 and five glass-ceramics (CD, CDc, EMHT, EMLT, and RL) in Group 2. The Student's

Table 1 RBCs and glass ceramic blocks specifications, compositions and characteristics

	Code	Manufacturer	Product name	Shade/ Lot numbers	Type	Composition		Filler size (µm)	Filler content (wt%/vol%)
						Matrix	Filler		
RBCs	BF	Shofu (Kyoto, Japan)	Beautifil II	A3/051520	Nanohybrid	Bis-GMA TEGDMA	Surface prereacted glass ionomer Multifunctional glass filler Nanofiller	0.01–4.0/ mean 0.8 0.01–0.02	83.3/68.6
	ES	Tokuyama Dental (Tokyo, Japan)	Estelite Sigma Quick	A3/158EY4	Suprananofill	Bis-GMA TEGDMA	Sillica/zirconia filler Composite filler Spherical submicron filler	0.1–0.3/mean 0.2	82/71
	F2	3M ESPE (St Paul, MN, USA)	Filtek Z250	A3/N699362	Microhybrid	Bis-GMA UDMA Bis-EMA	Sillica/zirconia filler	0.01–3.5	78/60
	F3	3M ESPE	Filtek Z350 XT	A3/N676525	Nanofill	Bis-GMA UDMA TEGDMA PEGDMA Bis-EMA	Nonaggregated silica/zirconia filler Aggregated silica/ zirconia cluster	Silica 0.02/ zirconia 0.004–0.011 0.6–20	78.5/63.3
	GD	GC (Tokyo, Japan)	Gradia Direct	A3/1406262	Microhybrid	UDMA	Microhybrid filler (no barium glass)	Mean 0.85	73/64
	HC	Kerr (Orange, CA, USA)	Herculite Precis	A3/5552583	Nanohybrid	Bis-GMA TEGDMA	Prepolymerized filler Sillica nanofiller Hybrid filler (barium glass)	30–50 0.02–0.05 Mean 0.4	78/59
	LU	3M ESPE	Lava™ Ultimate	A3 HT/NA42935	Resin nano ceramic	Bis-GMA UDMA Bis-EMA TEGDMA	SiO_2 ZrO_2 Aggregated ZrO_2/ SiO_2 cluster	0.02 0.004–0.011	—
	TC	Ivoclar Vivadent (Schaan, Liechtenstein)	Tetric N-Ceram	A3/U26780	Nanohybrid	Bis-GMA UDMA	Barium glass Ytterbium trifluoride Mixed oxide and copolymers	0.04–3.0	80–81/ 55–57
Glass Ceramics	CD	Dentsply Sirona	Celtra® Duo	A3 HT/5365411025	Zirconia-reinforced lithium-silicate (ZLS)	Zircornia	Lithium sillicate crystallites SiO_2, Li_2O, K_2O, P_2O_5, Al_2O_3, ZrO_2, CeO_2, Pigments	0.5–0.7	11% lithium disilicate 25% lithium silicate
	CDc	Heat-cured Celtra® Duo		A3 HT/5365411025					
	EMHT	Ivoclar Vivadent	IPS e.max CAD HT	A3/626409	Lithium disilicate	Crystalline lithium disilicate	SiO_2, 58–80% Li_2O 11–19% K_2O 0–13% ZrO_2 0–8% other coloring oxides	70%	—
	EMLT	Ivoclar Vivadent	IPS e.max CAD LT	A3/605330					
	RL	GENOSS (Suwon, Gyeonggi-do, South Korea)	rainbow™ LS	A3/19H27-01	Lithium disilicate	—	SiO_2, 60–82% Li_2O 10–20% ZrO_2 0–95 P_2O_5 0–8% CaO 0–5%	—	—

wt%, weight percentage; vol%, volume percentage; Bis-GMA, bisphenol A-glycidyl methacrylate; TEGDMA, triethyleneglycol dimethacrylate; PEGDMA, polyethylene glycol dimethacrylate; Bis-EMA, ethoxylated bisphenol-A-dimethacrylate; UDMA, urethane dimethacrylate

Table 2 CIE L^*, a^*, b^* values of RBCs and glass ceramics (1, 2, 3, and 4 mm) on white and black backing, and ΔL^*, Δa^* and Δb^* and TP of each RBC and glass ceramic in 1, 2, 3 and 4 mm

	Code	Thickness (mm)	Backing	L^*		a^*		b^*		ΔL^*		Δa^*		Δb^*		TP	
				Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
RBCs	BF	1	White	58.73	0.00	2.35	0.01	15.59	0.01	−8.71	0.04	−3.09	0.03	−9.30	0.04	13.11^{a}	0.05
			Black	50.02	0.04	−0.75	0.03	6.29	0.04								
		2	White	55.23	0.12	1.51	0.04	11.53	0.07	−4.05	0.13	−1.36	0.05	−2.74	0.07	5.07^{b}	0.08
			Black	51.18	0.01	0.15	0.02	8.79	0.01								
		3	White	53.53	0.01	0.99	0.01	10.23	0.01	0.08	0.05	−0.43	0.02	−0.30	0.03	0.53^{c}	0.02
			Black	53.62	0.05	0.56	0.02	9,92	0.03								
		4	White	55.25	0.01	0.88	0.02	10.49	0.04	0.18	0.20	−0.08	0.03	−0.13	0.06	0.27^{d}	0.16
			Black	55.43	0.20	0.81	0.02	10.36	0.04								
	ES	1	White	58.34	0.86	1.05	0.04	11.07	0.17	−10.92	0.10	−2.51	0.08	−8.13	0.18	13.85^{a}	0.90
			Black	47.42	0.66	−1.47	0.07	2.95	0.14								
		2	White	50.98	1.03	0.34	0.06	6.77	0.12	−1.28	0.14	−1.30	0.08	−2.11	0.27	3.06^{b}	0.64
			Black	49.07	0.79	−0.96	0.07	4.66	0.22								
		3	White	50.88	0.7	−0.33	0.02	5.70	0.08	−1.21	0.12	−0.41	0.04	−0.55	0.10	1.61^{c}	0.87
			Black	49.67	0.77	−0.74	0.03	5.15	0.09								
		4	White	49.76	0.69	−0.57	0.04	5.07	0.09	−1.22	0.09	−0.07	0.05	−0.33	0.09	1.47^{c}	0.57
			Black	48.54	0.63	−0.64	0.03	4.74	0.10								
	F2	1	White	60.70	0.02	1.58	0.01	14.59	0.01	−9.19	0.02	−2.69	0.02	−8.92	0.01	13.09^{a}	0.02
			Black	51.51	0.01	−1.12	0.02	5.67	0.01								
		2	White	54.57	0.01	0.92	0.02	10.60	0.01	−1.21	0.02	−1.32	0.02	−2.01	0.02	2.69^{b}	0.01
			Black	53.35	0.02	−0.40	0.01	8.60	0.01								
		3	White	53.09	0.01	0.32	0.01	9.49	0.01	−0.24	0.02	−0.42	0.01	−0.86	0.02	0.99^{c}	0.01
			Black	52.84	0.03	−0.10	0.01	8.62	0.02								
		4	White	52.93	0.00	0.16	0.01	9.36	0.01	0.12	0.03	−0.13	0.02	−0.14	0.01	0.24^{d}	0.01
			Black	53.06	0.03	0.02	0.02	9.22	0.01								
	F3	1	White	61.88	0.22	0.26	0.06	12.09	0.12	−9.94	0.29	−2.20	0.09	−8.39	0.15	13.19^{a}	0.32
			Black	51.94	0.14	−1.95	0.05	3.70	0.06								
		2	White	56.13	0.01	−0.24	0.01	8.23	0.01	−1.59	0.09	−1.15	0.06	−2.10	0.17	2.88^{b}	0.19
			Black	54.54	0.08	−1.39	0.06	6.13	0.17								
		3	White	55.76	0.02	−0.66	0.01	7.21	0.01	−1.14	0.06	−0.44	0.01	−0.53	0.02	1.33^{c}	0.06
			Black	54.61	0.05	−1.10	0.01	6.68	0.02								
		4	White	54.92	0.01	−0.82	0.01	7.04	0.01	−0.17	0.02	−0.11	0.02	−0.25	0.01	0.33^{d}	0.01
			Black	54.75	0.01	−0.93	0.02	6.79	0.01								
	GD	1	White	61.74	0.02	0.53	0.02	12.45	0.01	−13.76	0.03	−2.61	0.02	−10.52	0.02	17.52^{a}	0.02
			Black	47.97	0.01	−2.09	0.01	1.93	0.02								
		2	White	54.39	0.02	0.17	0.01	8.29	0.01	−2.52	0.02	−1.60	0.02	−3.21	0.01	4.39^{b}	0.01
			Black	51.86	0.01	−1.43	0.01	5.08	0.01								
		3	White	52.73	0.01	−0.32	0.01	6.89	0.01	−0.64	0.01	−0.74	0.02	−0.97	0.01	1.38^{c}	0.01
			Black	52.09	0.01	−1.06	0.01	5.92	0.01								
		4	White	52.52	0.03	−0.46	0.37	6.55	0.02	−0.09	0.03	−0.36	0.03	−0.42	0.03	0.60^{d}	0.31
			Black	52.43	0.02	−0.83	0.09	6.13	0.01								

Table 2 continued

	Code	Thickness (mm)	Backing	L^* Mean	L^* SD	a^* Mean	a^* SD	b^* Mean	b^* SD	ΔL^* Mean	ΔL^* SD	Δa^* Mean	Δa^* SD	Δb^* Mean	Δb^* SD	TP Mean	TP SD
RBCs	HC	1	White	59.24	0.03	−1.14	0.12	11.43	0.47	−7.64	0.02	−2.39	0.14	−7.90	0.04	11.25[a]	0.37
			Black	51.60	0.02	−3.54	0.03	3.54	0.01								
		2	White	54.93	0.02	−2.19	0.04	8.03	0.09	−1.13	0.04	−0.55	0.07	−0.47	0.15	1.35[b]	0.12
			Black	53.80	0.04	−2.74	0.03	7.56	0.09								
		3	White	53.90	0.01	−2.32	0.01	7.84	0.01	0.34	0.12	−0.34	0.02	−0.68	0.02	0.84[c]	0.05
			Black	54.24	0.12	−2.66	0.02	7.16	0.01								
		4	White	53.18	0.05	−2.50	0.02	6.72	0.03	0.57	0.06	−0.17	0.07	−0.14	0.02	0.62[d]	0.05
			Black	53.75	0.01	−2.67	0.07	6.57	0.01								
	LU	1	White	66.33	0.51	−0.51	0.05	6.67	0.08	−16.04	0.51	−1.47	0.04	−8.98	0.09	18.44[a]	0.49
			Black	50.30	0.01	−1.99	0.03	−2.32	0.02								
		2	White	58.50	0.02	−1.04	0.01	3.49	0.01	−3.34	0.02	−0.90	0.04	−3.57	0.02	4.97[b]	0.02
			Black	55.16	0.01	−1.94	0.02	−0.08	0.01								
		3	White	58.53	0.02	−1.44	0.01	1.70	0.01	−0.71	0.01	−0.47	0.04	−1.33	0.01	1.58[c]	0.01
			Black	57.82	0.01	−1.91	0.02	0.37	0.01								
		4	White	57.26	0.02	−1.49	0.03	2.02	0.01	−1.16	0.03	−0.28	0.03	−0.59	0.02	1.33[c]	0.02
			Black	56.10	0.02	−1.77	0.02	1.44	0.02								
	TC	1	White	61.73	0.09	−0.29	0.02	9.83	0.11	−12.11	0.02	−2.03	0.03	−8.79	0.09	15.10[a]	0.22
			Black	49.63	0.21	−2.32	0.03	1.04	0.11								
		2	White	52.69	0.11	−0.84	0.02	5.06	0.11	−0.36	0.02	−1.03	0.03	−2.23	0.02	2.49[b]	0.25
			Black	52.33	0.20	−1.88	0.02	2.83	0.23								
		3	White	52.54	0.11	−1.36	0.02	4.60	0.10	−0.10	0.01	−0.38	0.02	−0.56	0.11	0.69[c]	0.11
			Black	52.44	0.03	−1.74	0.01	4.04	0.02								
		4	White	52.24	0.14	−1.40	0.02	4.24	0.05	0.08	0.02	−0.16	0.04	−0.24	0.21	0.39[d]	0.15
			Black	52.31	0.31	−1.56	0.05	4.00	0.23								
Glass ceramics	CD	1	White	64.55	2.96	−0.52	0.26	10.67	0.35	−13.04	0.29	−1.93	0.25	−8.97	0.38	16.20[a]	0.20
			Black	51.51	1.97	−2.45	0.03	1.25	0.30								
		2	White	50.62	0.73	0.09	0.13	6.38	0.43	−3.78	0.76	−1.85	0.16	−4.67	0.43	6.29[b]	0.36
			Black	46.84	0.49	−1.76	0.06	1.70	0.17								
		3	White	49.82	0.38	−0.71	0.04	4.25	0.16	1.85	0.17	−0.92	0.13	−1.25	0.42	2.41[c]	0.18
			Black	51.67	1.55	−1.63	0.13	2.99	0.28								
		4	White	46.12	1.43	−0.72	0.18	1.81	0.57	−0.28	0.16	−0.90	0.32	−1.13	0.08	2.20[c]	0.20
			Black	45.83	1.62	−1.62	0.14	0.68	0.53								
	CDc	1	White	67.11	2.58	−1.49	0.09	11.06	0.51	−11.79	0.31	−1.35	0.18	−9.24	0.53	15.04[a]	0.50
			Black	55.31	1.54	−2.84	0.14	1.82	0.83								
		2	White	57.06	1.09	−1.16	0.19	5.93	0.52	−3.64	0.08	−1.44	0.32	−4.08	0.52	5.65[b]	0.49
			Black	53.43	0.69	−2.60	0.20	1.85	0.22								
		3	White	57.45	2.17	−1.07	0.33	4.37	0.64	0.53	0.77	−0.69	0.22	−0.60	0.44	1.52[c]	0.13
			Black	57.99	2.08	−1.75	0.38	3.77	0.72								
		4	White	53.00	1.53	−1.18	0.16	1.57	0.12	−1.00	0.85	−0.54	0.06	−0.37	0.34	1.31[c]	0.72
			Black	52.00	1.31	−1.72	0.11	1.19	0.38								

Table 2 continued

	Code	Thickness (mm)	Backing	L^*		a^*		b^*		ΔL^*		Δa^*		Δb^*		TP	
				Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Glass ceramics	EMHT	1	White	63.56	1.51	−0.93	0.07	8.41	0.11	−14.61	0.02	−1.43	0.09	−6.72	0.36	16.15^{a}	0.73
			Black	48.95	0.81	−2.36	0.05	1.69	0.29								
		2	White	52.25	1.34	−1.02	0.04	6.65	0.09	−5.53	0.09	−1.04	0.02	−3.85	0.04	6.81^{b}	0.76
			Black	46.72	0.58	−2.06	0.02	2.80	0.07								
		3	White	50.54	0.34	−1.38	0.04	5.45	0.16	−1.37	0.18	−0.52	0.06	−1.37	0.16	1.96^{c}	0.61
			Black	49.23	0.95	−1.90	0.04	4.08	0.15								
		4	White	47.03	0.38	−1.46	0.04	3.87	0.07	−1.30	0.09	−0.47	0.08	1.05	0.13	1.74^{d}	0.44
			Black	45.73	0.82	−1.94	0.06	2.82	0.13								
	EMLT	1	White	62.53	1.15	−0.79	0.10	12.20	0.30	−8.76	0.71	−1.72	0.04	−6.71	0.52	11.17^{a}	0.80
			Black	53.77	0.36	−2.51	0.10	5.49	0.43								
		2	White	56.48	0.78	−0.90	0.004	8.98	0.22	−3.17	0.48	−1.33	0.07	−3.01	0.32	4.57^{b}	0.12
			Black	53.31	0.84	−2.22	0.03	5.97	0.12								
		3	White	55.58	0.20	−1.34	0.02	8.25	0.20	−0.98	0.52	−0.50	0.04	−0.65	0.24	1.27^{c}	0.31
			Black	54.60	0.51	−1.83	0.02	7.61	0.14								
		4	White	53.48	0.41	−1.58	0.05	6.77	0.11	−0.85	0.53	−0.40	0.09	−0.60	0.15	1.12^{c}	0.07
			Black	52.62	0.35	−1.99	0.44	6.18	0.11								
	RL	1	White	58.75	0.39	1.74	0.04	13.61	0.17	−9.79	0.38	−2.24	0.04	−7.88	0.18	12.76^{a}	0.39
			Black	48.96	0.01	−0.50	0.02	5.73	0.01								
		2	White	49.01	0.50	1.89	0.09	10.73	0.16	−3.76	0.50	−1.76	0.09	−3.79	0.16	5.63^{b}	0.27
			Black	45.25	0.25	0.14	0.01	6.94	0.01								
		3	White	44.99	0.06	1.45	0.001	7.96	0.01	−0.55	0.29	−1.19	0.02	−1.54	0.15	2.03^{c}	0.22
			Black	44.45	0.27	0.26	0.01	6.42	0.15								
		4	White	49.53	0.28	0.41	0.02	7.71	0.02	0.07	0.27	−0.35	0.03	−0.45	0.02	0.63^{d}	0.04
			Black	49.60	0.01	0.06	0.02	7.26	0.01								

SD, Standard deviation
For TP, the same lowercase superscripts within a column of each of the RBCs and glass ceramics indicate no significant difference in different thicknesses (1, 2, 3 and 4 mm) (p<0.05).

t-test was used to compare TP, ΔL^*, Δa^*, and Δb^* of the RBCs (Group 1) with those of the glass-ceramic blocks (Group 2). All statistical analyses were performed using SPSS v.25 (IBM, Armonk, NY, USA) with a significance level of 0.05.

RESULTS

The mean ΔL^*, Δa^*, Δb^*, and TP values in each of the RBCs and glass-ceramic blocks are summarized in Table 2. The TP values of the RBCs and glass-ceramic blocks significantly decreased as the thickness of the materials increased (1, 2, 3, and 4 mm), except for ES, LU, CD, CDc, and EMLT, which did not show statistically significant differences between 3 mm and 4 mm (Table 3). As shown in Fig. 1 and Table 4, the TP values were reduced by an average of 76.7% in the RBCs and 59.4% in the glass-ceramics, especially from a thickness of 1 mm to 2 mm.

The TP values of the materials according to thickness are shown in Fig. 1. LU showed the greatest TP value among the materials at 1 mm and was significantly different from the lowest TP value of EMLT. At 2 mm, EMHT showed the highest TP value, which was significantly different from ES, F2, F3, GD, HC, and TC in the RBCs, and EMLT in the glass-ceramics. CD showed the highest TP value at 3 mm and 4 mm.

When the materials were divided into two groups, there was no statistically significant difference in the TP between the two groups at 1 mm thick. However, the differences in the TP between the two groups at 2, 3, and 4 mm thick were significantly different, and the average TP values at thicknesses of 2, 3, and 4 mm were greater in Group 2 (glass-ceramics) than in Group 1 (RBCs) (Table 4).

Table 3 TPs on each RBC and glass ceramic of 1, 2, 3 and 4 mm (Mean (SD))

	Code	Thickness			
		1 mm (SD)	2 mm (SD)	3 mm (SD)	4 mm (SD)
RBCs	BF	13.11 (0.05)^{aABC}	5.07 (0.08)^{bCD}	0.53 (0.02)^{cA}	0.27 (0.16)^{dA}
	ES	13.85 (0.90)^{aCD}	3.06 (0.64)^{bB}	1.61 (0.87)^{cCD}	1.47 (0.57)^{cBC}
	F2	13.09 (0.02)^{aABC}	2.69 (0.01)^{bB}	0.99 (0.01)^{cAB}	0.24 (0.01)^{dA}
	F3	13.19 (0.32)^{aBCD}	2.88 (0.19)^{bB}	1.33 (0.06)^{cBC}	0.33 (0.01)^{dA}
	GD	17.52 (0.02)^{aFG}	4.39 (0.01)^{bC}	1.38 (0.01)^{cBC}	0.60 (0.31)^{dA}
	HC	11.25 (0.37)^{aAB}	1.35 (0.12)^{bA}	0.84 (0.05)^{cAB}	0.62 (0.05)^{dA}
	LU	18.44 (0.49)^{aG}	4.97 (0.02)^{bCD}	1.58 (0.01)^{cCD}	1.33 (0.02)^{cBC}
	TC	15.10 (0.22)^{aDE}	2.49 (0.25)^{bB}	0.69 (0.11)^{cA}	0.39 (0.15)^{dA}
Glass ceramics	CD	16.20 (1.02)^{aEF}	6.29 (0.36)^{bEF}	2.41 (1.18)^{cF}	2.20 (0.20)^{cD}
	CDc	15.04 (0.05)^{aDE}	5.65 (0.49)^{bDE}	1.53 (0.13)^{cABC}	1.31 (0.72)^{dBC}
	EMHT	16.15 (0.73)^{aEF}	6.81 (0.76)^{bF}	1.96 (0.61)^{cE}	1.74 (0.44)^{dCD}
	EMLT	11.17 (0.80)^{aA}	4.57 (0.12)^{bC}	1.27 (0.31)^{cBC}	1.12 (0.07)^{cB}
	RL	12.76 (0.39)^{aABC}	5.63 (0.27)^{bDE}	2.03 (0.22)^{cDE}	0.63 (0.04)^{dA}

SD, Standard deviation

The same lowercase superscripts within a row indicate no significant difference for different thicknesses of the same RBCs and for different thicknesses of the same glass ceramics (p<0.05). The same uppercase superscripts within a column indicate no significant difference for different RBCs of the same thickness and for different glass ceramics of the same thickness (p<0.05).

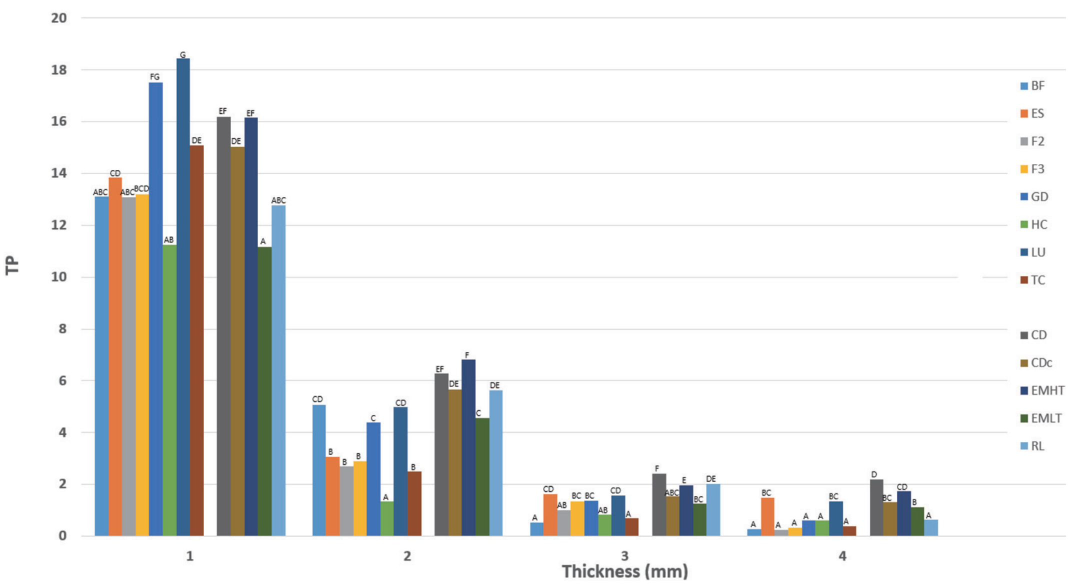

Fig. 1 TP for each of the RBCs and glass-ceramics according to thickness (1, 2, 3, and 4 mm). The same uppercase superscripts indicate no significant difference in the different RBCs and glass-ceramics with the same thickness (p<0.05).

In the ΔL^* analysis, there were statistically significant differences in thicknesses of 2 and 4 mm between the two groups, but no significant difference was seen in thicknesses of 1 and 3 mm. For Δa^* and Δb^*, significant differences were present in all thicknesses between the two groups (Table 4), and the average Δb^* absolute values were greater than those of Δa^* in all thicknesses on average (Table 4 and Fig. 2).

DISCUSSION

A colorimeter was used to measure the translucency under constant illumination (CIE standard illuminant D65) in this study. According to the manufacturer's instruction, the colorimeter has a 3 mm diameter measuring area. It uses 45° circumferential illumination and a 0° viewing angle for measuring precise areas of

Table 4 Student's t-test results for comparison of TP, ΔL^*, Δa^* and Δb^* between Group 1 (RBCs; BF, ES, F2, F3, GD, HC, LU and TC) and Group 2 (glass ceramics; CD, CDc, EMHT, EMLT and RL) (p<0.05)

		Thickness															
variables	Group (n)	1 mm				2 mm				3 mm				4 mm			
		Mean	SD	t	p	Mean	SD	t	p	Mean	SD	t	p	Mean	SD	t	p
TP	Group 1 (80)	14.44	2.33	0.24	0.81	3.36	1.26	−11.6	0.00*	1.12	0.49	−7.06	0.00*	0.66	0.51	−7.18	0.00*
	Group 2 (50)	14.26	2.83			5.79	1.07			1.84	0.78			1.25	0.74		
ΔL*	Group 1 (80)	−11.04	2.67	1.08	0.28	−1.94	1.28	8.62	0.00*	−0.45	0.67	−1.73	0.86	−0.21	0.70	3.01	0.04*
	Group 2 (50)	−11.60	3.21			−3.98	1.37			−0.22	1.67			−0.67	1.05		
Δa*	Group 1 (80)	−2.38	0.46	−8.35	0.00*	−1.15	0.31	5.70	0.00*	−0.45	0.12	8.61	0.00*	−0.17	0.16	10.10	0.00*
	Group 2 (50)	−1.73	0.36			−1.48	0.34			−0.75	0.29			−0.53	0.24		
Δb*	Group 1 (80)	−8.87	0.79	−4.87	0.00*	−2.30	0.89	10.87	0.00*	−0.72	0.31	5.13	0.00*	−0.28	0.17	7.09	0.00*
	Group 2 (50)	−7.90	1.25			−3.88	0.63			−1.08	0.49			−0.72	0.51		

SD, Standard deviation; t, t-value; p, p-value
The asterisk (*) denotes statistically significant difference in the thicknesses of each variable at the level 0.05.

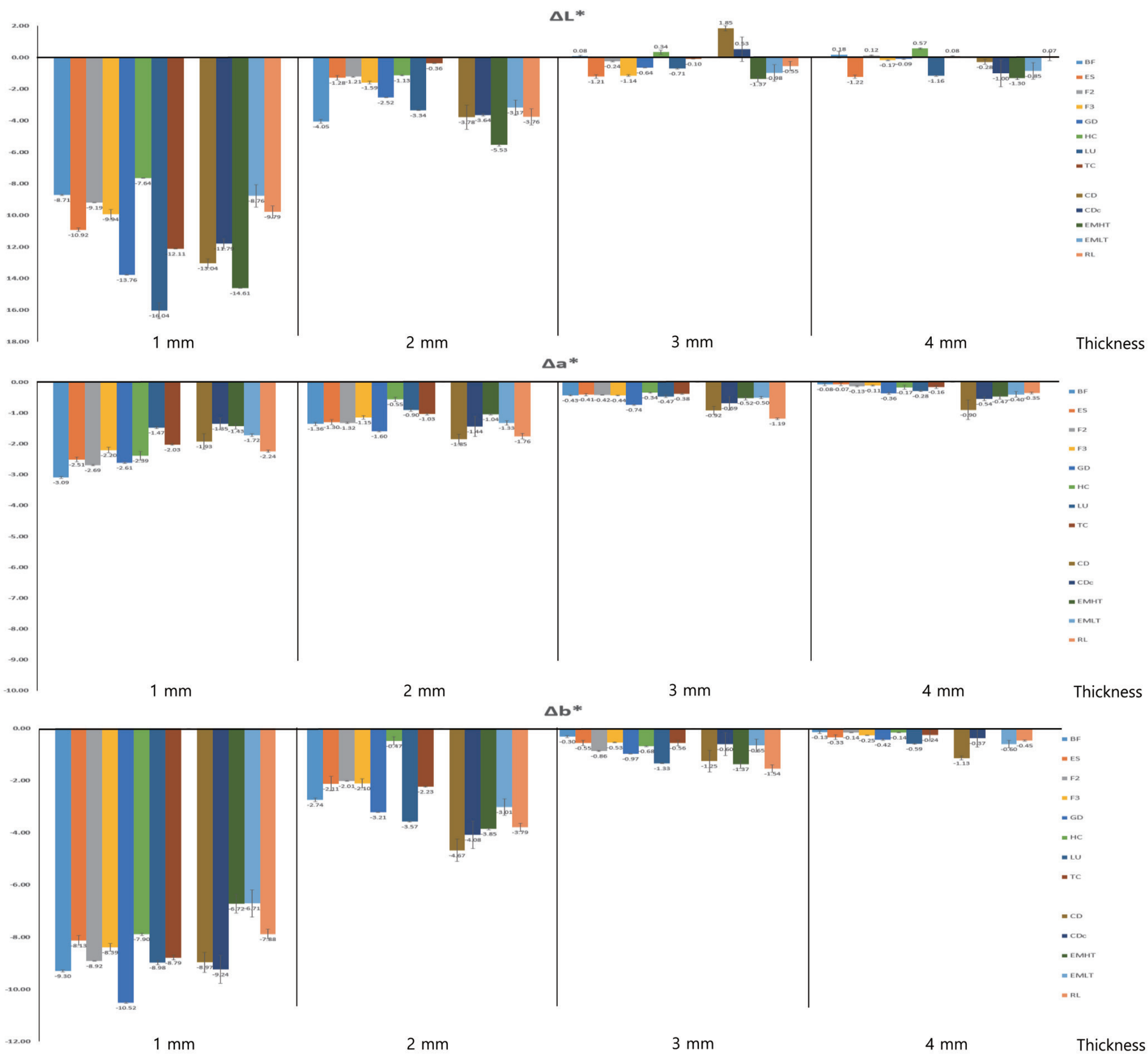

Fig. 2 ΔL^*, Δa^*, and Δb^* graphs for each of the RBCs and glass-ceramics at 1, 2, 3, and 4 mm thicknesses, respectively.

the sample surfaces, using a pulsed xenon lamp as the light source, which is diffused into a diffusion chamber. This illumination method illuminates the sample from all directions, with almost completely equal brightness. Additionally, the six high-sensitivity photocells filtered to match the CIE Standard Observer Response, ensuring the conditions are uniform for all measurements[31)].

Some studies reported that composite resins and dental ceramics' translucency decreased as the thickness increased[23,32,33)]. Kamishima *et al*. concluded that translucency increased exponentially as the thickness of resin composites was reduced regardless of their shade[32)]. They performed a correlation analysis for each shade of resin composite products and found that an exponential function most precisely expressed the relationship between thickness and the TP value. The present study found that the TP values decreased as the thickness of the materials increased, especially from a thickness of 1 mm to 2 mm, where the TP values dropped sharply by an average of 76.7% ((14.44−3.36)/14.44×100) in the RBCs and 59.4% ((14.26−5.79)/14.26×100) in the glass-ceramics (Fig. 1 and Table 4). Based on a recent study on translucency thresholds, translucency perceptibility difference threshold using CIELAB formula was reported to be 1.33 when 50:50% (50% negative answers and 50% positive answers) thresholds were calculated[34)]. In the present study, the translucency difference (ΔTP) value ranged from 8.04 to 13.47 in RBCs, and those of glass-ceramics ranged from 6.60 to 9.91 when the restoration materials were thickened from 1 mm to 2 mm. These changes would be clinically noticeable when the 1.33 threshold value is applied.

This study also found that the TP value of Group 1 (RBCs) decreased more significantly as the thickness of the material increased from 2 mm to 4 mm compared to Group 2 (glass-ceramics). The TP values at a thickness of 1 mm were not significantly different in the two groups (Table 4). This could suggest that RBCs exhibit translucency similar to that of glass-ceramics when used for restoration at a thickness of less than 1 mm. The results shown in Table 4 suggest that restoring teeth with glass-ceramics could present higher translucency than using RBCs when the thickness of the restoration is 2 mm because the average TP value was significantly greater in Group 2 (5.79) than in Group 1 (3.36) at a thickness of 2 mm. In this sense, if the clinicians want to mask the discoloration within 2 mm thickness of tooth, hiding it with the composites would be preferable to using the glass-ceramic.

Although the TP value of Group 2 (glass-ceramics) was significantly greater than that of Group 1 (RBCs), the TP values at 3 mm and 4 mm thicknesses were close to 0 in both the RBCs and glass-ceramics and the ΔTP value between 3 mm and 4 mm was under 1.33 (Table 3). Thus, RBCs or glass-ceramic restorations with a thickness of more than 3 mm became opaque, and the translucency of the 3 mm-thick restorations could not be distinguished from those of more than 3 mm. Therefore, if discoloration occurs deeper than 3 mm in the tooth, it would be successfully masked with composites or glass-ceramics.

The thickness of the restoration and the polymerization efficiency of the underlying resin luting agents could affect long-term clinical success because the transmission of light was significantly reduced as the thickness of the CAD-CAM blocks increased due to light scattering within the materials[35)]. A study also showed that the translucency and the irradiance showed a strong correlation with microhardness values in different cements[36)]. Some studies found that the increased thickness of resin composites and ceramic materials acted as an optical barrier to light reaching the resin cement and resin composites and that the translucency of the resin composites and ceramic materials also influenced the light intensity of the light-curing unit[37-41)]. Considering the low TP values of the 3 and 4 mm-thick glass-ceramics used in this study, the use of powerful curing light with a high radiant emittance and applying a longer light-curing time would be needed to provide sufficient radiant exposure for the underlying resin cement.

Regarding the fact that TP was calculated from the ΔL^*, Δa^*, and Δb^* values, ΔL^*, Δa^*, and Δb^* were individually analyzed in both the RBCs and glass-ceramics. As shown in Fig. 2, the changes in ΔL^* and Δb^* values were greater than those of Δa^* according to the thickness, which could indicate that the TP value was more affected by ΔL^* and Δb^* than by Δa^*. It could also be assumed that the RBCs and glass-ceramics became darker and bluish as they thickened. A previous study proposed that layering lighter-colored and higher shade numbers of RBC could increase the yellowish hue and lightness in the restoration of a deep cavity[19)]. Additionally, the changes in ΔL^*, Δa^*, and Δb^* values depending upon the thickness were generally higher in Group 1 (RBCs) than those in Group 2 (glass-ceramics). As shown in Table 4, the average absolute values of TP, ΔL^*, Δa^*, and Δb^* were higher in Group 1 than in Group 2 except for TP, Δa^*, and Δb^* at a thickness of 1 mm, and ΔL^* at 3 mm. The difference between the RBC and glass-ceramic groups might be due to the combined effects of the components and the microstructure of these materials, which needs further investigation.

The translucency of RBCs is influenced by the distribution and composition of the matrix and fillers, the size and shape of the filler particles, and the refractive index[42-45)]. A previous study evaluated the translucency of RBCs only, with different shades within each product line, and concluded that significant differences were observed in translucency among the different shade numbers within each RBC product line[19)]. Thus, the identical shade A3 was employed in the glass-ceramics as well as the RBCs in this study. Lee suggested categorizing the translucency of RBCs as low, medium, and high based on TP values from 13 to 18 using 1 mm-thick RBC specimens[11)]. When applying the criteria to the present study, BF, ES F2, F3, and HC were categorized as low-translucent resin composites, TC as medium, and GD and LU as high-translucent resin composites.

It was reported that the translucency was high when the refractive indices of the resin matrix and filler were similar[46]. Barium glass and ytterbium trifluoride are radiopaque fillers with refractive indices of 1.98 and 1.53, respectively. As the resin monomer's refractive indices are between 1.49 and 1.56, it is more similar to ytterbium trifluoride than barium glass[46]. Considering the RBCs' composition in Table 1, the TP values of TC were higher than those of BF, ES, F2, and F3 because the use of ytterbium trifluoride might increase the translucency of TC compared to using barium glass alone. GD and LU could be categorized as high-translucent resin composites based on the criteria suggested by Lee[11]. GD is a micro-hybrid RBC and contains fillers with an average size of 0.85 μm. It is the only RBC that does not include barium glass, indicating that the lack of radiopaque fillers might increase the translucency of RBCs. The high TP value of LU could be attributed to silica and zirconia nanoparticles in its composition, which are embedded in a highly cross-linked resin matrix[47]. LU is resin nanoceramic containing nanometer-sized filler particles with diameters smaller than the wavelength of visible light, and these particles cause less light scattering and increased light transmission, thereby improving translucency[15].

Likewise, the optical properties and translucency of dental ceramics are influenced by chemical composition, microstructure, the shape and average size of the particles, the distribution of the crystalline phase, adaptation of the refractive indices of the crystalline phase and matrix, the fabrication procedures, and porosity[48,49]. Based on the TP values in 1 mm-thick glass-ceramics, CD and EMHT presented higher TP values than those of EMLT and RL. It was reported that smaller crystals and higher crystalline content lead to lower translucency[50]. In the present study, EMHT exhibited higher TP values than those of EMLT. This may be due to the 0.8–1.5 μm crystal sizes of EMHT, whereas EMLT had smaller crystals (0.2–0.8 μm) at a higher density[51].

CD is zirconia-reinforced lithium silicate (ZLS), in which ZrO_2 particles are incorporated into the glass matrix to improve the mechanical properties of the glass-ceramics[52,53]. Although some studies regarding the effect of zirconia content on the translucency of ZLS revealed the negative impact of zirconia content on the translucency[54,55], the TP value of CD was relatively high, which was comparable to that of EMHT in this study. The study concluded that glass-ceramic was essentially opaque when the zirconia content was 10%. However, another study found that 35% ZrO_2–65% SiO_2 glass-ceramic was transparent and could be a candidate for use as a dental crown in terms of translucency[51]. However, the details on CD's zirconia content were not sufficient to correlate the content with translucency. According to Awad *et al.*, zirconia-reinforced glass-ceramic was reported to have a higher mean TP value than lithium disilicate ceramic because of the differences in grain size and crystalline structures[56]. The researchers explained that the crystals in zirconia-reinforced glass-ceramic had a mean grain size of 500 to 700 nm after crystallization, which was four to eight times smaller than the lithium disilicate crystallites in lithium disilicate ceramic[52,56]. This could explain the higher TP values seen in CD compared to EMLT and RL in this study.

The TP value of CDc was lower than that of CD. The crystal size in glass-ceramics was affected by firing and this sintering caused more compact interlocking of the microstructures in the crystals[57], alterations in the crystalline structure, and changes in surface specifications[58,59], which led to lower translucency. Although the TP value was higher in CD than that in CDc, fired CD (also known as CDc in this study) presented higher fracture toughness and Vickers hardness values than unfired CD[60] because decreased zirconia grains after the crystallization process could also contribute to the higher fracture strength of CDc[52,61]. Considering the TP value and mechanical properties of CD and CDc, CDc could be used more generally in posterior teeth, whereas CD could be used in anterior teeth or posterior teeth with less occlusal loading.

CONCLUSIONS

Within the limitations of this *in-vitro* study, the following conclusions may be drawn:

1. The TP of RBCs and glass-ceramics decreased as the thickness increased, especially from 1 mm to 2 mm.
2. The TP value of RBCs was more significantly decreased as the thickness of the material increased from 2 mm to 4 mm than that of glass-ceramics.

ACKNOWLEDGMENTS

This study was supported by Yonsei University College of Dentistry Research Fund 6-2019-0015.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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