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RESEARCH ARTICLE

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How will surface conditioning methods influence the translucency and color properties of CAD-CAM resin-matrix ceramics with different thicknesses?

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Abstract

Objective: It was aimed to evaluate the effect of various surface-conditioning methods on the translucency and color properties of resin-matrix ceramics (RMCs) with different types and thicknesses.

Materials and methods: Rectangle-shaped RMCs were prepared from Voco Grandio, Brilliant Crios, Lava Ultimate, GC Cerasmart, and Vita Enamic blocks at 0.5 and 1.0 mm thicknesses. Specimens were divided into four groups: control, airborne-particle abrasion (APA), 2 and 3 W Er, Cr:YSGG laser irradiations (L^{2W}, L^{3W}) (n = 15). The color values of specimens were recorded before and after surface-conditioning using a spectrophotometer. The translucency parameter (RTP_{00}) and color difference (ΔE_{00}) values were calculated. Data were statistically analyzed using three-way ANOVA and Tukey post hoc tests.

Results: The translucencies of RMCs decreased after all surface-conditioning procedures. L caused more decline in translucency of materials than APA. All ΔE_{00} values were under the acceptability threshold except for APA-applied Voco Grandio at 0.5 mm. Differences in ΔE_{00} values between APA and L^{3W} groups were significant ($P<0.05$); while differences between L^{2W} and L^{3W} groups were insignificant ($P > .05$). In all experimental groups, ΔE_{00} values decreased with increasing thickness of RMCs.

Conclusions: L and APA significantly affected the translucency and color properties of RMCs. APA was found more favorable than L.

Clinical significance: Clinicians should carefully use surface conditioning methods, considering their impact on the optical characteristics of RMCs, especially when the restoration is thin.

KEYWORDS
airborne-particle abrasion, color difference, Er,Cr:YSGG laser, resin-matrix ceramic, translucency parameter

1 | INTRODUCTION

The intention to successfully emulate the physical properties of enamel and dentin tissues has led to the emergence of high-performance multiphase materials, in which a dominant ceramic network is reinforced by a cross-linked polymeric matrix.[1-3] These so-called resin-matrix ceramics (RMCs)[4,5] unify the best characteristics of ceramics and resin composites,[6-13] and can be sub-categorized by the way of incorporation of ceramic into the polymeric matrix, as resin nano-ceramic and polymer-infused ceramic.[14-16] Numerous studies have conducted on their mechanical properties, reporting superb fatigue resistance to allow the manufacture of ultra-thin noninvasive restorations,[17-19] enhanced machinability,[20] acceptable wear resistance,[21] low abrasiveness to the opposite dentition,[21] and promising bond-strength values.[14] Additionally, this material group only requires polishing, can be glazed and individualized with the aid of light-cure stains, does not require firing,[5,21] and can be repaired intraorally.[20,21]

In clinical trials, it is well-documented that poor resin bonding can jeopardize the long-term viability of a restoration by leading to manifold mechanical and biological complications.[22-25] The implementation of surface conditioning is indispensable to remove the loose contaminated surface, to form micro-retentive grooves, to enhance wettability on the intaglio surface of restoration, and thereby to facilitate a strong bond between restoration and luting cement by the genesis of micromechanical interlocking.[24,26-29]

In contemporary dentistry, several conditioning techniques are in use to provide a suitable surface for adherent and substrate.[2,9,23,26] Of these, the drive to use air-borne particle abrasion (APA) and laser irradiation (L) has increased in intensity.[26] APA functions by throwing abrasive particles (grits) against the intaglio surface of restoration from a predefined distance,[30,31] and L functions by removing the inorganic content from the intaglio surface of restoration with the help of micro-explosions and vaporization.[24,27] Although, a plethora of laser systems is available[32]; the use of erbium, chromium-doped yttrium, scandium, gallium, and garnet (Er,Cr:YSGG) laser (2.780 nm wavelength) is widespread.[23,24] Superior resin-bonding is feasible with these surface-conditioning methods; however, alterations in surface topography (roughness) have been depicted to occur after these methods and this may jeopardize the esthetic success of restoration by affecting translucency and color characteristics.[9,32]

Translucency can be expressed as the relative light transmission of the material over white and black backgrounds.[33] Translucency parameter (TP) has been used for various studies; including the present one, in response to the demand for quantifying translucency.[34] The TP value is zero when the material is completely opaque.[35] The main components that significantly affect translucency of the restoration are filler particle-size,[36] the thickness of the material,[13,29,35,37] surface texture,[9,29] metal oxides,[14,16,36,38] and the characteristics of the underlying foundation.[11,26,36] Color difference (ΔE) value is generated to describe the numerical distance between two colors. Today, CIEDE2000 formula recommended by *International Commission on Illumination* is more preferred to calculate ΔE, instead of CIELAB formula which suffers from lack of perceptual uniformity.[11,34]

The influence of different surface conditioning methods on the optical behaviors of various ceramic systems including RMC,[9] lithium disilicate,[9,29,35] leucite,[29] nano-fluorapatite,[29] and zirconia-based ceramics[32,33] was demonstrated. It was stated that in lithium disilicate ceramics[9,29,35] and RMCs,[9] the surface conditioning with APA and L tends to cause color changes and reduce translucency. In zirconia-based ceramics, where surface conditioning was performed before the sintering process, increased translucency has been reported. More color changes were observed in the zirconia specimens conditioned before sintering compared to the ones conditioned after sintering.[32] With the advancements in manufacturing technologies, novel blocks for RMCs were introduced.[5] To the best knowledge of the authors, the effect of surface conditioning methods on the translucency and color properties of these novel RMC materials has not been evaluated yet and therefore, it was aimed to compare the previously-evaluated RMCs with the novel ones by investigating the influence of different surface conditioning methods (APA, L^{2W}, and L^{3W}) on their translucency and color properties. The null hypotheses were those surface conditioning methods would not differentially influence the color properties of RMC specimens with various types and thicknesses, and there would be no statistically significant influence of surface conditioning methods on the data of relative translucency parameter (RTP_{00}).

2 | MATERIALS AND METHODS

2.1 | Preparation of specimens

The characteristics of CAD/CAM RMC materials used in this study are shown in Table 1. A total number of 600 rectangular-shaped specimens of shade A2/2M2 were cut from the blocks of five different CAD/CAM restorative materials, namely (a) Voco Grandio (VG), (b) Brilliant Crios (BC), (c) Lava Ultimate (LU), (d) GC Cerasmart (GC), (e) Vita Enamic (VE), into slices in two different thicknesses ($12 \times 14 \times 0.5$ mm^3 and $12 \times 14 \times 1.0$ mm^3) by using a precision cutting machine (Micracut 201, Metkon Instruments Ltd, Bursa, Turkey). The veneer surfaces of all specimens underwent grounding with silicon carbide papers in a sequence of 600-, 800-, 1200-, and 2000-grit, by using a grinding machine (Gripo 2 V, Metkon Instruments Ltd, Bursa, Turkey) at 100 rpm/min for 15 seconds under a constant flow of water until reaching 0.5 ± 0.1 and 1.0 ± 0.1 mm in thickness. Subsequently, these surfaces were scrubbed by using disc (Diapol Twist, EVE Ernst Vetter Gmbh, Germany) and paste (Diamond Twist SCO, Premier Dental Gmbh, USA) with the aid of an electric handpiece at 10000 rpm for 20 seconds. To measure the thicknesses, a digital caliper (Mitutoyo Corp., Tokyo, Japan) was preferred. Following ultrasonic cleaning (Biosonic Ultrasonic Cleaner UC1-110, Coltene Whaledent, Cuyahoga Falls, Ohio) for 5 minutes in distilled water, all specimens were kept in distilled water for 24 hours. Figure 1 shows a schematic illustration of specimen preparation and research design.

2.2 | Color readings before surface conditioning

Before surface conditioning, initial color-readings of specimens were done in a viewing booth under a standardized illumination source D65 by using a digital spectrophotometer (VITA Easyshade Compact, VITA Zahnfabrik, Bad Säckingen, Germany). Three short-term repeated reflectance measurements without replacement were made by positioning the measuring tip at the center of the specimen by a single operator and the results were averaged. For color difference evaluation, the grey photographic card (L^* = 25.7, a^* = 2.8, b^* = 8.4) was used as a background, and color coordinates of each specimen were recorded as L^*_0, C^*_0, H^*_0.

TABLE 1 Compositions, shades, and manufacturers of the CAD/CAM resin-matrix ceramic materials used in this study

Material	Composition	Shade	Manufacturer	Batch (Lot)
Voco Grandio (VG)	• Organic part: methacrylates • Inorganic part: 86 wt% filler	LT A2	VOCO GmbH, Cuxhaven, Germany	1 925 249
Brilliant Crios (BC)	• Organic part: cross-linked methacrylates • Inorganic part: 70.7 wt% barium glass and amorphous silica	LT A2	Coltène Whaledent AG, Altstatten, Switzerland	I24143
Lava Ultimate (LU)	• Organic part: Bis-GMA, Bis-EMA, UDMA, TEGDMA • Inorganic part: 80 wt% silica and zirconia nanoparticles and zirconia/silica nanoclusters	LT A2	3 M ESPE, St. Paul, MN, USA	N644403
GC Cerasmart (GC)	• Organic part: Bis-MEPP, UDMA, DMA • Inorganic part: 71 wt% silica and barium glass nanoparticles	LT A2	GC Dental Products, Aichi, Japan	1 509 052
Vita Enamic (VE)	• Organic part: UDMA, TEGDMA • Inorganic part: 86 wt% glass ceramic (SiO_2, Al_2O_3, Na_2O, K_2O, and other oxides)	T 2 M2	Vita Zahnfabrik, Bad Säckingen, Germany	43 230

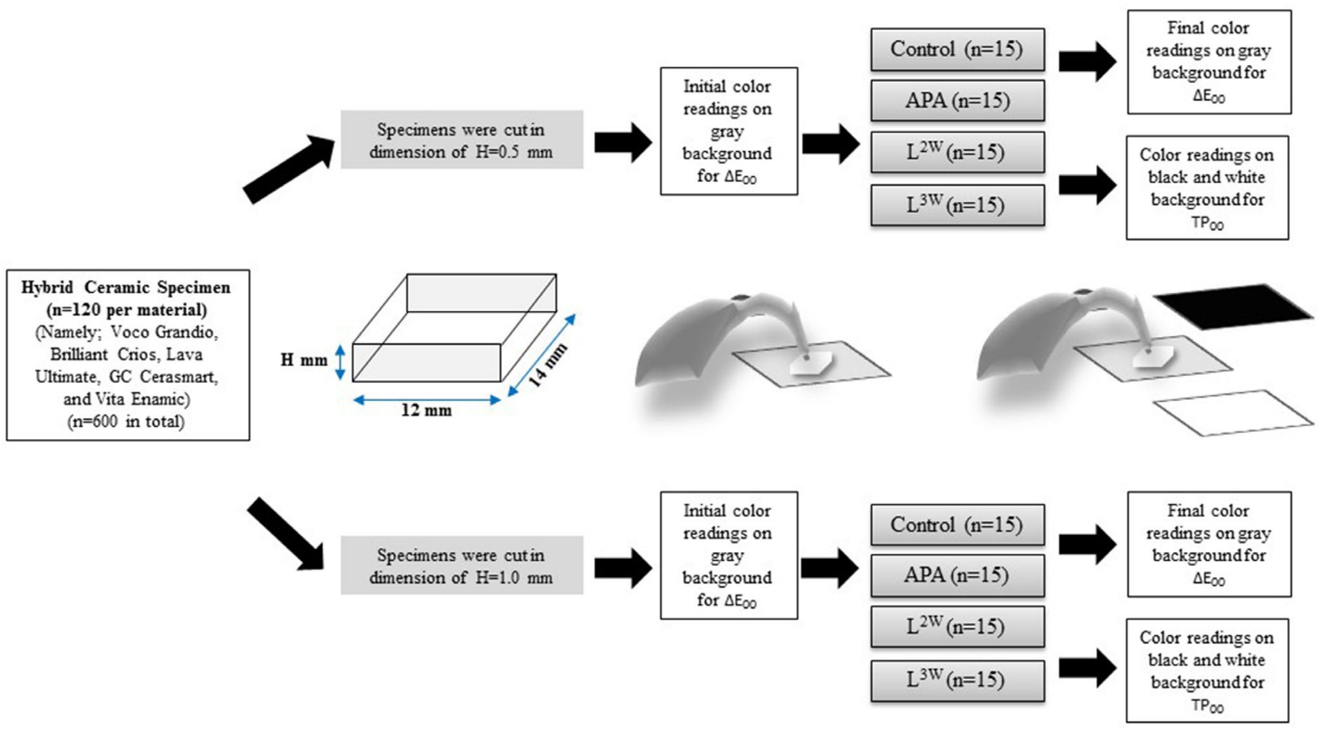

FIGURE 1 Schematic representation of specimen preparation and test groups [Color figure can be viewed at wileyonlinelibrary.com]

2.3 | Surface conditioning

Specimens of the control group remained untouched. In L group, an Er,Cr:YSGG laser (Waterlase MD, Biolase, Irvine, California) was used to entirely irradiate the intaglio surface of each specimen for 20 seconds by using an MG6 sapphire tip on a noncontact hard tissue mode at two different energy levels (2 and 3 W), a repetition rate of 20 Hz, and a pulse duration of 140 μs with water/airflow of 65% and 55%, respectively. The sapphire tip was aligned perpendicular to the cementation surfaces of ceramic specimens at a distance of 1 mm. For the APA group, 50 μm Al_2O_3 (Korox, Bego, Bremen, Germany) particles were thrown to entirely abrade the intaglio surface of each specimen for 20 seconds at an air pressure of 2 bar from a distance of 10 mm. Following ultrasonic cleaning (Biosonic Ultrasonic Cleaner UC1-110, Coltene Whaledent, Cuyahoga Falls, Ohio) for 5 minutes in distilled water, all specimens were kept in distilled water for 24 hours.

2.4 | Color readings after surface conditioning

After surface conditioning, final color-readings of specimens were done and L^*_1, C^*_1, H^*_1 coordinates of each specimen were generated on grey background with the abovementioned manner. Subsequently, following the CIEDE2000 (ΔE_{00}) formula was used to perform computations:

$$\Delta E^*_{00} = \sqrt{\left(\frac{\Delta L'}{kLSL}\right)^2 + \left(\frac{\Delta C'}{kCSC}\right)^2 + \left(\frac{\Delta H'}{kHSH}\right)^2 + RT\left(\frac{\Delta C'}{kCSC}\right)^2\left(\frac{\Delta H'}{kHSH}\right)^2}$$

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ represent the differences in lightness, chroma, and hue between two sets of color coordinates measured over grey background, respectively. A total of 0.80 ΔE_{00} unit and 1.80 ΔE_{00} unit were regarded as perceptibility and acceptability thresholds for color differences, respectively.[39]

2.5 | Evaluation of relative translucency

Color coordinates of each specimen in control groups and surface-conditioned groups were measured over black and then over white backgrounds, and recorded as L^*_b, C^*_b, H^*_b and L^*_w, C^*_w, H^*_w, respectively. Relative translucency (RTP_{00}) was then calculated by using the following formula:

$$RTP_{00}:\sqrt{\left(\frac{L'_w-L'_b}{kLSL}\right)^2+\left(\frac{C'_w-C'_b}{kCSC}\right)^2+\left(\frac{H'_w-H'_b}{kHSH}\right)^2+RT\left(\frac{C'_w-C'_b}{kCSC}\right)^2\left(\frac{H'_w-H'_b}{kHSH}\right)^2}$$

where the subscripts "b" and "w" for L', C', and H' refer to lightness, chroma, and hue of each layer over the black and the white backgrounds, respectively. In both formulae, weighting functions (S_L, S_C, and S_H) represent the adjustment of total color difference for variation in the location of the color difference pair in L, a, b coordinates; parametric factors (k_L, k_C, and k_H,) represent the correction terms for experimental conditions; and rotation function (R_T) accounts for the interaction between chroma and hue differences in the blue region. All parametric factors were set to 1.

2.6 | Statistical analysis

Obtained data were statistically analyzed with a package (IBM SPSS Statistics v22, IBM Corp., Chicago, USA). The conjecture of data normality was ratified with the aid of the Shapiro Wilk Test ($P < 0.05$). To investigate the influence of 3 variables (material type, material thickness, and surface conditioning) on ΔE_{00} and TP_{00} values, three-way analysis of variances (3-way ANOVA) was conducted. In significant interactions, 1-way ANOVA was used to determine from what level of factors the difference arises and Tukey's Honestly Significant Difference post hoc test was, subsequently, used for multiple comparisons. Values of $P < .05$ were accepted as statistically significant.

3 | RESULTS

3.1 | Color difference

In accordance with the results of three-way ANOVAs, ΔE_{00} values were significantly affected by all aforementioned variables and their interactions ($P \leq .001$) except material × thickness interaction ($P = .065$) (Table 2). The mean ΔE_{00} values and SD with Tukey post hoc comparisons results are presented in Table 3 for 0.5 mm-thick specimens and in Table 4 for 1.0 mm-thick specimens.

ΔE_{00} values were observed to decrease due to the increase in thickness in the materials. ΔE_{00} values decreased significantly with increasing thickness in all air-borne abraded materials ($P < .05$). Except for BC-L^{2W} ($P = .039$) and GC-L^{2W} ($P \leq .001$) groups, ΔE_{00} values did not change statistically significantly with increasing thickness in all materials conditioned with L^{2W} and L^{3W} laser ($P > .05$).

For 0.5-mm-thick specimens, imperceptible color difference was detected only in the VG-L^{2W} group ($\Delta E_{00} \leq 0.8$). ΔE_{00} value for the VG-APA was found to be above the threshold of clinical acceptability ($\Delta E_{00} > 1.8$). Color differences in all other groups showed perceptible but clinically acceptable values ($0.8 < \Delta E_{00} \leq 1.8$). For all ceramic groups, the difference between the values of L groups and those of APA groups revealed statistical significance except for the difference between L^{2W} and APA groups of GC ($P = .322$) and for the difference between L^{2W} and APA groups of LU ($P = 1.000$). It was also observed that the highest ΔE_{00} value was in VG and the lowest values were in LU and GC groups in APA-applied RMC materials, and the difference between LU and GC groups was not statistically significant ($P = .264$). Although more color difference occurred in RMC materials conditioned with L^{3W} compared to the groups conditioned with L^{2W}; the difference was not statistically significant ($P > .05$). In the L-applied groups, the lowest ΔE_{00} values were detected in VG and BC groups and the differences between these groups were insignificant ($P = .209$ for 2 W, $P = .984$ for 3 W). Although, the highest values were observed in the LU, GC, and VE groups, respectively; the differences among these groups were not significant ($P > .05$).

For 1.0-mm-thick specimens, none of the groups exceeded the acceptability threshold. Color differences in VG-APA, LU-L^{2W}, VE-L^{2W}, LU-L^{3W}, GC-L^{3W}, and VE-L^{3W} groups showed perceptible but clinically acceptable values ($0.8 < \Delta E_{00} \leq 1.8$). The rest of the groups revealed an imperceptible color difference ($\Delta E_{00} < 0.8$). The highest and lowest ΔE_{00} values were observed in the VG-APA group and LU-L^{3W} group, respectively. No statistically significant difference was found among the surface conditioning methods for BC specimens. While the difference between the values of APA applied groups and those of L^{2W} applied groups did not show statistical significance, except for VC ($P \leq .001$); the difference between the values of the APA applied groups and those of the L^{3W} applied groups was statistically significant ($P < .05$), except for BC ($P = .168$). In all RMC materials conditioned with APA, it was found that the highest ΔE_{00} value belonged to the VG group, the lowest values belonged to the BC and GC groups, and that the difference between the groups exhibiting the lowest values was not statistically significant ($P = 1.000$). For all RMC materials, L^{3W} applied groups had more color difference compared to L^{2W} applied groups; however, the difference was not statistically significant ($P > .05$). In the laser applied groups, the lowest ΔE_{00} values were in the VG and BC groups and the differences were statistically insignificant ($P = .107$ for L^{2W}, $P = 1.000$ for L^{3W}). The highest values appeared in LU, VE, and GC groups, respectively; however, the differences among these groups were statistically insignificant ($P > .05$).

TABLE 2 Three-way ANOVA results of color difference (ΔE_{00}) values

Source	Type III sum of Squares	df	Mean square	F	Sig.
Corrected model	71.053	29	2.450	28.447	0.000
Intercept	477.034	1	477.034	5538.752	0.000
Material (A)	6.430	4	1.607	18.664	0.000
Thickness (B)	19.071	1	19.071	221.435	0.000
Surface conditioning method (C)	5.765	2	2.882	33.467	0.000
A * B	0.768	4	0.192	2.228	0.065
A * C	29.675	8	3.709	43.069	0.000
B * C	5.591	2	2.796	32.460	0.000
A * B * C	3.752	8	0.469	5.446	0.000
Error	36.173	420	0.086		
Total	584.260	450			
Corrected total	107.226	449			

TABLE 3 Color difference (ΔE_{00}) values (Mean ± SD) of CAD/CAM resin-matrix ceramic materials at 0.5 mm thickness

	Surface conditioning methods		
Resin-matrix ceramic materials	APA	L^{2W}	L^{3W}
VG	$1.98 \pm 0.22^{A,a}$	$0.75 \pm 0.17^{B,b}$	$0.89 \pm 0.38^{B,b}$
BC	$1.47 \pm 0.37^{A,b}$	$0.82 \pm 0.20^{B,b}$	$0.91 \pm 0.20^{B,b}$
LU	$1.02 \pm 0.21^{B,c}$	$1.28 \pm 0.35^{A,B,a}$	$1.44 \pm 0.43^{A,a}$
GC	$0.95 \pm 0.17^{B,c}$	$1.24 \pm 0.38^{A,B,a}$	$1.37 \pm 0.40^{A,a}$
VE	$1.59 \pm 0.23^{A,b}$	$0.99 \pm 0.18^{B,a,b}$	$1.22 \pm 0.21^{B,a}$

Note: Different capital letters indicate differences in same row; different lower case letters indicate differences in same column for each ceramic type.

Abbreviations: APA, air-borne particle abrasion; BC, Brilliant Crios; L^{2W}, laser irradiation with 2.0 W power; L^{3W}, laser irradiation with 3.0 W powerLU, Lava Ultimate; GC, GC Cerasmart; VE, Vita Enamic; VG, Voco Grandio.

TABLE 4 Color difference (ΔE_{00}) values (Mean ± SD) of CAD/CAM resin-matrix ceramic materials at 1.0 mm thickness

	Surface conditioning methods		
Resin-matrix ceramic materials	APA	L^{2W}	L^{3W}
VG	$1.43 \pm 0.28^{A,a}$	$0.51 \pm 0.20^{B,b}$	$0.60 \pm 0.23^{B,b}$
BC	$0.61 \pm 0.08^{A,c}$	$0.64 \pm 0.14^{A,b}$	$0.67 \pm 0.10^{A,b}$
LU	$0.76 \pm 0.31^{B,b}$	$1.06 \pm 0.23^{A,B,a}$	$1.26 \pm 0.29^{A,a}$
GC	$0.49 \pm 0.22^{B,c}$	$0.74 \pm 0.24^{A,B,a,b}$	$0.94 \pm 0.37^{A,a,b}$
VE	$0.70 \pm 0.20^{B,b,c}$	$0.90 \pm 0.26^{A,B,a}$	$1.18 \pm 0.28^{A,a}$

Note: Different capital letters indicate differences in same row; different lower case letters indicate differences in same column for each ceramic type.

Abbreviations: APA, air-borne particle abrasion; BC, Brilliant Crios; L^{2W}, laser irradiation with 2.0 W power; L^{3W}, laser irradiation with 3.0 W power; LU, Lava Ultimate; GC, GC Cerasmart; VE, Vita Enamic; VG, Voco Grandio.

3.2 | Relative translucency

In accordance with the results of three-way ANOVAs, RTP_{00} values of specimens were influenced by the material thickness, material type, surface conditioning method, as well as the interaction terms of these three variables ($P \leq .001$) (Table 5). The mean RTP_{00} values and standard deviations of control and surface-conditioned groups of each RMC are depicted in Table 6 for 0.5-mm-thick specimens and in Table 7 for 1.0-mm-thick specimens.

Increasing material thickness significantly decreased the RTP_{00} value in each group ($P < .05$). For each material at both thicknesses, the highest RTP_{00} values were found in the unconditioned group, followed, in order, by the APA, L^{2W}, and L^{3W} groups. The translucencies of RMC materials statistically significantly decreased ($P < .05$)

TABLE 5 Three-way ANOVA results of relative translucency parameter (RTP_{00}) values

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	7213.718	39	184.967	495.894	0.000
Intercept	123 320.279	1	123 320.279	330 619.692	0.000
Material (A)	494.349	4	123.587	331.336	0.000
Thickness (B)	5690.177	1	5690.177	15 255.273	0.000
Surface conditioning method (C)	876.693	3	292.231	783.467	0.000
A * B	51.602	4	12.900	34.586	0.000
A * C	44.312	12	3.693	9.900	0.000
B * C	22.553	3	7.518	20.154	0.000
A * B * C	34.033	12	2.836	7.603	0.000
Error	208.879	560	0.373		
Total	130 742.876	600			
Corrected total	7422.597	599			

TABLE 6 Relative translucency parameter (RTP_{00}) values (Mean ± SD) of CAD/CAM resin-matrix ceramic materials at 0.5 mm thickness

	Surface conditioning methods			
Resin-matrix cramic materials	Control	APA	L^{2W}	L^{3W}
VG	$19.76 \pm 0.62^{A,b}$	$18.99 \pm 0.46^{A,a}$	$18.06 \pm 0.70^{B,a}$	$17.01 \pm 0.60^{C,a}$
BC	$18.88 \pm 0.57^{A,c}$	$17.60 \pm 0.94^{B,c}$	$16.70 \pm 0.62^{C,b}$	$15.58 \pm 0.56^{D,b}$
LU	$19.18 \pm 0.78^{A,b,c}$	$18.02 \pm 1.03^{B,b,c}$	$16.69 \pm 0.82^{C,b}$	$16.37 \pm 0.79^{C,a,b}$
GC	$20.67 \pm 0.39^{A,a}$	$18.51 \pm 0.97^{B,a,b}$	$16.74 \pm 0.91^{C,b}$	$16.71 \pm 0.60^{C,a}$
VE	$18.03 \pm 0.51^{A,d}$	$16.69 \pm 0.82^{B,d}$	$14.78 \pm 0.50^{C,c}$	$12.87 \pm 0.74^{D,c}$

Note: Different capital letters indicate differences in same row; different lower case letters indicate differences in same column for each ceramic type.
Abbreviations: APA, air-borne particle abrasion; BC, Brilliant Crios; L^{2W}, laser irradiation with 2.0 W power; L^{3W}, laser irradiation with 3.0 W power; LU, Lava Ultimate; GC, GC Cerasmart; VE, Vita Enamic; VG, Voco Grandio.

TABLE 7 Relative translucency parameter (RTP_{00}) values (Mean ± SD) of CAD/CAM resin-matrix ceramic materials at 1.0 mm thickness

	Surface conditioning methods			
Resin-matrix ceramic materials	Control	APA	L^{2W}	L^{3W}
VG	$12.89 \pm 0.42^{A,b}$	$12.63 \pm 0.62^{A,a,b}$	$11.59 \pm 0.54^{B,a}$	$10.18 \pm 0.43^{C,a}$
BC	$11.70 \pm 0.44^{A,c}$	$10.80 \pm 0.53^{B,c}$	$10.01 \pm 0.49^{B,b}$	$8.94 \pm 0.46^{C,b}$
LU	$13.04 \pm 0.51^{A,a,b}$	$12.36 \pm 0.48^{A,b}$	$11.41 \pm 0.58^{B,a}$	$10.53 \pm 0.34^{C,a}$
GC	$13.80 \pm 0.42^{A,a}$	$13.28 \pm 0.44^{A,a}$	$11.62 \pm 0.52^{B,a}$	$10.54 \pm 0.61^{C,a}$
VE	$11.20 \pm 0.47^{A,c}$	$10.48 \pm 0.29^{A,c}$	$9.55 \pm 0.42^{B,b}$	$8.59 \pm 0.43^{C,b}$

Note: Different capital letters indicate differences in same row; different lower case letters indicate differences in same column for each ceramic type.
Abbreviations: APA, air-borne particle abrasion; BC, Brilliant Crios; L^{2W}, laser irradiation with 2.0 W power; L^{3W}, laser irradiation with 3.0 W power; LU, Lava Ultimate; GC, GC Cerasmart; VE, Vita Enamic; VG, Voco Grandio.

after all surface conditioning procedures except for VG-APA-0.5 mm (P = .185), VG-APA-1.0 mm (P = 1.000), LU-APA-1.0 mm (P = .467), GC-APA-1.0 mm (P = .946), and VE-APA-1.0 mm (P = .324) groups.

For 0.5 mm-thick specimens, the differences between the RTP_{00} values of the APA group and those of the unconditioned group were statistically significant ($P < .05$), except the difference between VG-unconditioned and VG-APA ($P > .05$). The RTP_{00} values of the APA group were statistically significantly higher than those of L^{2W} applied materials except for VG ($P < .05$). The RTP_{00} values of L^{3W} applied materials were statistically significantly lower than those of L^{2W} applied materials except for LU and GC ($P < .05$). In unconditioned RMC groups, GC had significantly more translucent properties than other materials ($P < .05$). In APA, VG and GC presented the highest RTP_{00} values, respectively and the difference between these groups was not statistically significant ($P > .05$). In L^{2W} groups, VG revealed superior RTP_{00} values. In L^{3W} groups; VG, GCC, and LU exhibited the highest RTP_{00} values, respectively; however, the differences among these groups were not statistically significant ($P > .05$). In all groups, VE exhibited the lowest RTP_{00} value.

For 1.0 mm-thick specimens, all L^{2W} and L^{3W} applied RMCs showed significantly less translucency than APA applied RMCs ($P < .05$) except for the difference between BC-APA and BC-L^{2W} groups ($P = .168$). The RTP_{00} values of L^{3W} applied materials were statistically significantly lower than those of L^{2W} applied materials. In unconditioned ceramic groups, the highest RTP_{00} values were in the GC and LU, and the difference was not found to be statistically significant ($P = .218$). In the APA group, GC and VG exhibited superior RTP_{00} values, respectively; however, the difference between these groups was statistically insignificant ($P > .05$). In L^{2W} and L^{3W} groups, GCC, VG, and LU exhibited the highest RTP_{00} values, respectively; however, the differences among these groups were not statistically significant ($P > .05$). In all groups (unconditioned, APA, L^{2W}, and L^{3W}), VE and BC presented the lowest RTP_{00} values, and the difference between these groups was not statistically significant ($P > .05$).

4 | DISCUSSION

This study examined the impact of surface conditioning methods on the optical features of RMC specimens of two thicknesses. According to the results, it could be seen that RTP_{00} values were significantly influenced after surface conditioning methods, except for 0.5 mm-VG-APA and 1.0 mm-BC-APA. Apart from this, color differences were detected between conditioned and unconditioned specimens, and the surface conditioning methods differentially affected RMCs of various thicknesses. Therefore, the null hypotheses were rejected.

In order to enhance marginal adaptation, prevent micro-leakage, obtain high retention, and to increase restored tooth fracture resistance, durable adhesion-joint is required.[2,25] Surface conditioning methods are clinically useful in increasing surface roughness and thus wettability.[9] This is reinforced by the Wenzel Formula which proves that wetting is increased by surface roughness for contact angles less than 90°.[28] From the physical perspective, it can be assumed that smooth surfaces are less advantageous than rough ones in terms of bond-strength.[14,28] Supportively, it has been reported that surface-conditioned ceramics have shown promising performances in terms of bond-strength.[10] However, alterations in surface topography have been depicted to occur after surface-conditioning methods[23,27,35,38] and this can endanger the optical behaviors of restorative materials due to diffused reflection.[9,35,38]

By the results of this study, VE revealed the lowest RTP_{00} values among all RMC groups. The difference in translucency can be due to a number of factors. First, VE is a polymer infiltrated ceramic network, which consists of a porous feldspathic ceramic matrix and cross-linked polymers.[14,31] It includes a significant amount of aluminum oxide (Al_2O_3) in its ceramic-matrix composition,[14] and this is highly effective in increasing opacity values.[14,36] Second, APA with Al_2O_3 cannot attack the opaque Al_2O_3 portion of VE as particles used for APA protocol have a hardness similar to that of the particles found in the ceramic composition.[26] Third, it is known that particles with a diameter smaller than the wavelength of the visible light lead to less light scattering.[37] Micrometer-sized filler particles of VE might explain lower light transmission in comparison with others. Fourth, the ceramic matrix consists of metal oxide opacifiers like titanium oxide (TiO_2) and zirconium oxide (ZrO_2), which act as scattering centers and adversely influence the light transmission.[36] Fifth, large inconsistencies of refractive index between the reinforcing filler and the polymeric matrix lead to increased opacity values due to multiple reflection and refraction at the matrix phase interface.[14,36] The refractive indices of the UDMA, Bis-GMA, Bis-EMA, TEGDMA, TiO_2, Al_2O_3, and ZrO_2 are quoted as 1.48, 1.55, 1.53, 1.46, 2.49, 1.77, and 2.22, respectively. Ordinary radiopaque fillers, such as those including barium, strontium, and zirconium, present refractive indices of approximately 1.55.[36,40] As TiO_2 has the highest refractive index among all, it exhibits the supreme mismatch with the resin matrix, which explains why VE exhibits higher opacity. Sixth, the di-methacrylate Bis-GMA is commonly used as a base monomer in polymeric matrices of RMCs.[40] It is noted that Bis-GMA which does not present in VE, exhibits more translucent nature than UDMA and TEGDMA as Bis-GMA has a refractive index closer to the silica and zirconia filler systems than that of UDMA and TEGDMA.[40]

In terms of RTP_{00}, BC presented similar behavior with VE in 1 mm-thick specimens. It showed the second-lowest RTP_{00} values after the VE group. The presence of inorganic pigments (ferrous oxide and titanium dioxide) in its composition may be an explanation for the inferiority in terms of translucency. As stated, TiO_2 has the highest refractive index among all. This tends to form the greatest mismatch with the resin matrix and increases opacity values.[14,36,40]

This study also proved that, among unconditioned RMCs, GC revealed the highest RTP_{00} values in both thicknesses. This may be attributed to its chemistry. GC is a flexible nano-ceramic in which dispersed fillers (silica and barium glass) are embedded in the polymeric matrix.[8,21] It does not contain any opacifying agent.[21] The filler particles in GC are smaller than those in others.[3] Moreover, the refractive indices of Bis-MEPP and UDMA are close to those of silica and barium glass fillers. All may explain why GC exhibits higher RTP_{00} values.

Haas et al[36] investigated the impact of different opacifiers on the translucency of experimental dental composite resins and proved the opacifying effect of metal oxides by reporting a number of results: (a) All opacifiers (TiO_2, ZrO_2, and Al_2O_3 in descending order) decreased L^* value; (b) all opacifiers exhibited a little shift to the red pole of the a^* coordinate, with ZrO_2 revealing the greatest one; (c) TiO_2 and ZrO_2 depicted a big shift to the yellow pole of the b^* coordinate; however, Al_2O_3 showed a little shift to the blue pole; (d) The highest color difference value was detected for TiO_2, followed, in order, by ZrO_2, and Al_2O_3.

It is apparent that, among surface-conditioned 0.5-mm-thick specimens, VG exhibited superior RTP_{00} values. This can be correlated with Vicker's micro-hardness of VG as abrasives generally rely upon a difference in hardness between the abrasive agent and the ceramic material being worked upon. Technically, a much harder abrasive will cut faster and deeper; or shallower pits can be formed on hard surfaces. Alamoush et al[8] reported that the VE exhibited the highest micro-hardness, followed by VG, LU, BC, and CS, respectively. Albero et al[1] highlighted the strong correlation between micro-hardness and inorganic content. Corroborating our above-mentioned prediction, VG is one of the ceramic groups which exhibits the highest inorganic content, includes strong metal-oxide (ZrO_2), presents superior micro-hardness, and thereby is less-affected from conditioning.

Among surface-conditioned 1.0-mm-thick specimens, GC and VG revealed the highest RTP_{00} values, respectively; and the difference was insignificant. The reason for this behavior of VG is above-explained. Contrary to what might be expected, although GC has the lowest micro-hardness among others[8]; it exhibited superior translucency. This issue may be correlated with the chemistry of GC. Supportively, it has been stated that the compositional differences might be factors contributing to the differences in esthetic outcomes.[21,40]

For 0.5 mm-thick specimens, RTP_{00} value significantly decreased after all surface conditioning methods, except for airborne-particle-abraded VG specimens. This may be attributed to the fact that it exhibits the highest reinforcing inorganic content among others and superior micro-hardness.[8] Therefore, without endangering the RTP_{00} values, APA protocol can be safely used to condition the cementation surface of VG. On the other hand, for 1.0 mm-thick specimens, RTP00 value insignificantly decreased after APA conditioning, except for air-borne particle abraded BC, and significantly decreased after laser applications (2 and 3 W). It can be thought that the dark visual effect of roughness obtained by APA protocol is masked due to the thickness of specimens.[29] From this point of view, APA can be recommended for all RMCs, except BC; although hydrofluoric acid etching is recommended as a conditioning method by the manufacturer of VE. However, the same is not true for laser applied specimens as the dark visual effect produced by laser application is too heavy (deeper transformed zone or higher roughness[23,27]) to mask. The porosity formed on the cementation surface after laser irradiation caused an increase in the scattering of incident light and a drop in RTP_{00} values. This decrease was more prominent in specimens conditioned with L^{3W} as a higher power setting has a higher tendency to form micro-porosities.[9] This finding is not in accordance with those of the study by Harorli et al,[25] reporting no differences among 1.5, 2, and 3 W power settings for Er,Cr:YSGG laser, and can be attributed to the fact that Harorli et al[25] conducted laser irradiation on indirect composite resin specimens.

Previous studies stated that decreasing the thickness of material allows a greater amount of incident light transmission.[13,37] Supportively, Turgut et al[35] highlighted that thinner ceramics exhibit higher translucency. This is in accordance with the results of the current study as 0.5 mm-thick specimens were more translucent than 1.0-mm-thick specimens and as ΔE_{00} values were higher for 0.5 mm-thick specimens.

Regarding ΔE_{00} units, for 0.5-mm-thick specimens, only VG-L^{2W} group exhibited imperceptibility, and only VG-APA was found to be above the threshold of clinical acceptability. Others indicated perceptible but clinically acceptable ΔE_{00} units. It can be thought that the thinner and less opaque RMCs may have become more opaque after surface conditioning depending on the more translucent nature of these ceramics, whose texture differences can be detected more clearly. In the 1 mm thickness group, lower ΔE_{00} units were detected. This provides consistency with the previous study.[29] All groups were below the acceptability threshold, and imperceptible color differences were found in several 1-mm-thick RMC groups. This may be related to the thickness of the specimens.[29] The opaque appearance formed on the cementation surface of these thicker specimens was successfully camouflaged, resulting in lower ΔE_{00} units.

White, grey, and black can be defined as neutral colors that have no hue.[41] In many studies[9,38,42-44] where background shade is not a variable, neutral grey was preferred as a background to minimize the effect of background hue on the color measurement of the specimens and to standardize the process. In the current study, this arrangement was done to allow the investigation to focus on only the effects of the variables. Generally, spectrophotometers have been preferred for instrumental color determination.[9,13,32,36,38] However, spectrophotometers suffer from edge loss phenomenon due to the small window size that may influence the accuracy and reliability of measurements.[45] Even so, in comparison with visual observation, the use of spectrophotometer increases accuracy by 33% and provides 93.3% success.[46,47]

The current study has several limitations. The long-pulsed laser was used. However, ultra-short pulsed femtosecond lasers limit temperature distribution, reduce energy loss on the surface, and thereby minimize thermal destruction. Surface topographies of the conditioned-specimens were not examined. One size of Al_2O_3 particles for APA protocol was used. Thermal aging was not conducted. Despite its edge-lose phenomenon, the spectrophotometer was preferred. Further studies need to be performed.

5 | CONCLUSIONS

Within the limitations of the current study, the following conclusions can be drawn: (a) Tested surface conditioning methods influenced the translucency and color properties of the materials, (b) Laser-irradiated groups exhibited inferior translucency in comparison with APA, (c) Both in 0.5 mm- and 1.0 mm-thick specimens, GC revealed superior translucency, (d) 1.0-mm-thick ceramic specimens camouflaged influence of surface conditioning methods more effectively than thinner specimens, (e) For LU, GC and, VE RMCs of 1.0 mm thickness, the use of APA application is recommended because it did not have a significant effect on the RTP_{00} value of the stated materials, and the resulting color differences were clinically imperceptible, (f) Dental practitioners should carefully prefer surface conditioning methods, considering their impact on the optical characteristics of RMC, especially when the restoration is thin.

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REFERENCES

1. Albero A, Pascual A, Camps I, Grau-Benitez M. Comparative characterization of a novel cad-cam polymer-infiltrated-ceramic-network. *J Clin Exp Dent*. 2015;7(4):e495-e500.
2. Helbling F, Özcan M. Adhesion of resin cement to contemporary hybrid ceramic and polymeric CAD/CAM materials: effect of conditioning methods and ageing. *J Adhes Sci Technol*. 2019;33(8):886-902.
3. Emsermann I, Eggmann F, Krastl G, Weiger R, Amato J. Influence of pretreatment methods on the adhesion of composite and polymer infiltrated ceramic cad-cam blocks. *J Adhes Dent*. 2019;21(5):433-443.
4. Sulaiman TA. Materials in digital dentistry-a review. *J Esthet Restor Dent*. 2020;32(2):171-181.
5. Blatz MB, Conejo J. The current state of chairside digital dentistry and materials. *Dent Clin North Am*. 2019;63(2):175-197.
6. Awada A, Nathanson D. Mechanical properties of resin-ceramic CAD/CAM restorative materials. *J Prosthet Dent*. 2015;114(4):587-593.
7. Coldea A, Swain MV, Thiel N. Mechanical properties of polymer-infiltrated-ceramic-network materials. *Dent Mater*. 2013;29(4):419-426.
8. Alamoush RA, Silikas N, Salim NA, Al-Nasrawi S, Satterthwaite JD. Effect of the composition of CAD/CAM composite blocks on mechanical properties. *Biomed Res Int*. 2018;2018(1):1-8. https://doi.org/10.1155/2018/4893143.
9. Kurtulmus-Yilmaz S, Cengiz E, Ongun S, Karakaya I. The effect of surface treatments on the mechanical and optical behaviors of CAD/CAM restorative materials. *J Prosthodont*. 2019;28(2):e496-e503.
10. Oz FD, Canatan S, Bolay S. Effects of surface treatments on the bond strength of composite resin to hybrid computer-assisted design/manufacturing blocks. *J Adhes Sci Technol*. 2019;33(9):986-1000.
11. Pulgar R, Lucena C, Espinar C, et al. Optical and colorimetric evaluation of a multi-color polymer-infiltrated ceramic-network material. *Dent Mater*. 2019;35(7):e131-e139.
12. Spitznagel FA, Boldt J, Gierthmuehlen PC. CAD/CAM ceramic restorative materials for natural teeth. *J Dent Res*. 2018;97(10):1082-1091.
13. Gunal B, Ulusoy MM. Optical properties of contemporary monolithic CAD-CAM restorative materials at different thicknesses. *J Esthet Restor Dent*. 2018;30(5):434-441.
14. Duarte S, Sartori N, Phark J-H. Ceramic-reinforced polymers: CAD/CAM hybrid restorative materials. *Curr Oral Heal Reports*. 2016; 3(3):198-202.
15. Eldafrawy M, Greimers L, Bekaert S, et al. Silane influence on bonding to CAD-CAM composites: an interfacial fracture toughness study. *Dent Mater*. 2019;35(9):1279-1290.
16. Sonmez N, Gultekin P, Turp V, Akgungor G, Sen D, Mijiritsky E. Evaluation of five CAD/CAM materials by microstructural characterization and mechanical tests: a comparative in vitro study. *BMC Oral Health*. 2018;18(1):5.
17. Kassem AS, Atta O, El-Mowafy O. Fatigue resistance and microleakage of CAD/CAM ceramic and composite molar crowns. *J Prosthodont*. 2012;21(1):28-32.
18. Magne P, Schlichting LH, Paranhos MPG. Risk of onlay fracture during pre-cementation functional occlusal tapping. *Dent Mater*. 2011;27 (9):942-947.
19. Aboushelib MN, Elsafi MH. Survival of resin infiltrated ceramics under influence of fatigue. *Dent Mater*. 2016;32(4):529-534.
20. Alp G, Subaşı MG, Johnston WM, Yilmaz B. Effect of different resin cements and surface treatments on the shear bond strength of ceramic-glass polymer materials. *J Prosthet Dent*. 2018;120(3):454-461.
21. Bajraktarova-Valjakova E, Korunoska-Stevkovska V, Kapusevska B, Gigovski N, Bajraktarova-Misevska C, Grozdanov A. Contemporary dental ceramic materials, a review: chemical composition, physical and mechanical properties, indications for use. *Open Access Maced J Med Sci*. 2018;6(9):1742-1755.
22. Awad MM, Albedaiwi L, Almahdy A, et al. Effect of universal adhesives on microtensile bond strength to hybrid ceramic. *BMC Oral Health*. 2019;19(1):1-7.
23. Barutcigil K, Barutcigil Ç, Kul E, Özarslan MM, Buyukkaplan US. Effect of different surface treatments on bond strength of resin cement to a CAD/CAM restorative material. *J Prosthodont*. 2019;28(1):71-78.
24. Cengiz-Yanardag E, Kurtulmus Yilmaz S, Karakaya I, Ongun S. Effect of different surface treatment methods on micro-shear bond strength of CAD-CAM restorative materials to resin cement. *J Adhes Sci Technol*. 2019;33(2):110-123.
25. Harorli OT, Barutcugil C, Kirmali O, Kapdan A. Shear bond strength of a self-etched resin cement to an indirect composite: effect of different surface treatments. *Niger J Clin Pract*. 2015;18(3):405-410.
26. Borges GA, Sophr AM, De Goes MF, Sobrinho LC, DCN C. Effect of etching and airborne particle abrasion on the microstructure of different dental ceramics. *J Prosthet Dent*. 2003;89(5):479-488.
27. Demirtag Z, Culhaoglu AK. Surface roughness of ceramic-resin composites after femtosecond laser irradiation, sandblasting or acid etching and their bond strength with and without silanization to a resin cement. *Oper Dent*. 2019;44(2):156-167.
28. Marshall SJ, Bayne SC, Baier R, Tomsia AP, Marshall GW. A review of adhesion science. *Dent Mater*. 2010;26(2):11-16.
29. Turgut S, Bağiş B, Korkmaz FM, Tamam E. Do surface treatments affect the optical properties of ceramic veneers? *J Prosthet Dent*. 2014;112(3):618-624.
30. Khurshid Z, Najeeb S, Zafar MS, Sefat F. *Advanced Dental Biomaterials*. 1st ed. Duxford: Woodhead Publishing; 2019.
31. Campos F, Almeida CS, Rippe MP, De Melo RM, Valandro LF, Bottino MA. Resin bonding to a hybrid ceramic: effects of surface treatments and aging. *Oper Dent*. 2016;41(2):171-178.
32. Kurtulmus-Yilmaz S, Önöral Ö, Aktore H, Ozan O. Does the application of surface treatments in different sintering stages affect flexural strength and optical properties of zirconia? *J Esthet Restor Dent*. 2020;32(1):81-90.
33. Turgut S. Optical properties of currently used zirconia-based esthetic restorations fabricated with different techniques. *J Esthet Restor Dent*. 2020;32(1):26-33.
34. Salas M, Lucena C, Herrera LJ, Yebra A, Della Bona A, Pérez MM. Translucency thresholds for dental materials. *Dent Mater*. 2018;34(8): 1168-1174.
35. Turgut S, Bagis B, Ayaz EA, Korkmaz FM, Ulusoy KU, Bagis YH. How will surface treatments affect the translucency of porcelain laminate veneers? *J Adv Prosthodont*. 2014;6(1):8-13.
36. Haas K, Azhar G, Wood DJ, Moharamzadeh K, Van Noort R. The effects of different opacifiers on the translucency of experimental dental composite resins. *Dent Mater*. 2017;33(8):e310-e316.
37. Awad D, Stawarczyk B, Liebermann A, Ilie N. Translucency of esthetic dental restorative CAD/CAM materials and composite resins with respect to thickness and surface roughness. *J Prosthet Dent*. 2015;113(6):534-540.
38. Kurt M, Turhan Bal B. Effects of accelerated artificial aging on the translucency and color stability of monolithic ceramics with different surface treatments. *J Prosthet Dent*. 2019;121(4):712.e1-712.e8.
39. Paravina RD, Ghinea R, Herrera LJ, et al. Color difference thresholds in dentistry. *J Esthet Restor Dent*. 2015;27(suppl 1):S1-S9.

40. Azzopardi N, Moharamzadeh K, Wood DJ, Martin N, Van Noort R. Effect of resin matrix composition on the translucency of experimental dental composite resins. *Dent Mater*. 2009;25(12):1564-1568.
41. Shokry TE, Shen C, Elhosary MM, Elkhodary AM. Effect of core and veneer thicknesses on the color parameters of two all-ceramic systems. *J Prosthet Dent*. 2006;95(2):124-129.
42. Bayindir F, Koseoglu M. The effect of restoration thickness and resin cement shade on the color and translucency of a high-translucency monolithic zirconia. *J Prosthet Dent*. 2020;123(1):149-154.
43. Pecho OE, Ghinea R, Perez MM, Della Bona A. Influence of gender on visual shade matching in dentistry. *J Esthet Restor Dent*. 2017;29 (2):E15-E23.
44. Chen XD, Hong G, Xing WZ, Wang YN. The influence of resin cements on the final color of ceramic veneers. *J Prosthodont Res*. 2015;59(3):172-177.
45. Bolt RA, Bosch JJ, Coops JC. Influence of window size in small-window colour measurement, particularly of teeth. *Phys Med Biol*. 1994;39:1133-1142.
46. Chu SJ, Trushkowsky RD, Paravina RD. Dental color matching instruments and systems. Review of clinical and research aspects. *J Dent*. 2010;38(2):e2-e16.
47. Llena C, Lozano E, Amengual J, Forner L. Reliability of two color selection devices in matching and measuring tooth color. *J Contemp Dent Pract*. 2011;12:19-23.

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