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The Effect of Brand, Thickness, and Abutment Substrate on the Masking Ability of Monolithic Zirconia Ceramics

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ABSTRACT

The goal of the present study was to determine the minimum thickness of monolithic zirconia required to achieve an acceptable masking ability and to examine how brand, thickness, and abutment substrate influenced that masking ability (ΔE). Seventy-two A2-shade monolithic zirconia disc specimens in various thicknesses (1.0, 1.5, and 2.0 mm) were fabricated using three brands: Nacera® Pearl 1, DD cubeX2 and XTCERA TT. A spectrophotometer was used to determine the CIELab values of the specimens, which were placed on a D4-shade resin composite and white acrylic (control) substrates. The ΔE was calculated and compared with the acceptable (AT = 5.5) and perceptible (PT = 2.6) tolerance thresholds. Further investigation was conducted on 72-disc specimens from the monolithic zirconia brand with the best masking ability on D3-shade resin composite and semi-precious alloy. Using two-way ANOVA, the interaction of thickness, brand, and abutment substrate on ΔE was investigated. Nacera® Pearl 1 at 1.5 mm thickness was sufficient to achieve AT on a D4-shade resin composite substrate, whereas 2.0 mm of DD cubeX2 and XTCERA TT were required. Nacera® Pearl 1 further testing on two other substrates requires thicknesses of 1.5 mm and 1.0 mm, respectively. Only the Nacera® Pearl 1 group achieved PT on D3- and D4-shade resin composite (2.0 mm) and semi-precious alloy substrates (1.5 mm). Brand, thickness, and abutment substrate influenced the ΔE ($p < 0.001$). To achieve an acceptable masking ability, the minimum thickness of monolithic zirconia tested on D3- and D4-shade resin composite and semi-precious alloy should be around 1.5 mm to 2.0 mm.

Keywords: *Aesthetics; discolouration; monolithic zirconia; masking ability; translucency*

INTRODUCTION

Metal-free restorations have evolved in response to a demand for a more attractive alternative in prosthodontic management, as they have similar light-scattering qualities to natural tooth structure (Hegde *et al.*, 2011). Due to its outstanding mechanical qualities (Vichi *et al.*, 2016; Abdulmajeed *et al.*, 2017; Guncu *et al.*, 2023), and lack of ceramic chipping, monolithic zirconia as a full ceramic restoration, has increased in popularity (Lopez-Suarez *et al.*, 2017). As a result of its improved optical properties, monolithic zirconia may be one of the preferred materials for anterior teeth. Although lithium disilicate has better optical properties than monolithic zirconia (Church *et al.,* 2017; Shahmiri *et al.,* 2018), it masks discoloured teeth poorly (Succaria & Morgano, 2011). Therefore, when masking is required, the partial translucency of monolithic zirconia is advantageous.

The masking ability of monolithic zirconia restoration is influenced by manufacturing factors such as the level of translucency and thickness of the material used (Abdulmajeed *et al.*, 2017; Tabatabaian *et al.*, 2019), as well as clinical factors such as the shade of the underlying abutment (Kumagai *et al.*, 2013; Malkondu *et al.*, 2016; Tabatabaian *et al.*, 2016; Capa *et al.*, 2017). Furthermore, material composition (Sakka *et al.*, 2001; Vasylkiv *et al.*, 2003), grain size (Jiang *et al.*, 2011; Ebeid *et al.*, 2014), sintering duration (Ebeid *et al.*, 2014), and porosity of the material will affect the translucency of monolithic zirconia restoration (Heffernan *et al.,* 2002; Vagkopoulou *et al.*, 2009). As a result, achieving an optimal aesthetic result with monolithic zirconia restoration is challenging (Skyllouriotis *et al.*, 2017; Zhang *et al.*, 2022).

To evaluate a restoration's masking ability, the colour difference can be measured in the CIELAB system using the formula $\Delta E^{*} = [(L^{*}_{2} - L^{*}_{1})^{2} + (a^{*}_{2} - a^{*}_{1})^{2} + (b^{*}_{2} - b^{*}_{1})^{2}]^{1/2}$ where L^{*} denotes the lightness, a^{*} denotes red/green value and b^{*} denotes yellow/blue value. The perceptible tolerance threshold ranges from 1 to 5.5 ΔE units (Lindsey & Wee, 2007; Ishikawa-Nagai *et al.*, 2009; Ghinea *et al.,* 2010), while the acceptable tolerance thresholds are 2.6, 3.3 and 3.7 ΔE units (Paravina *et al.,* 2002; Lee *et al.*, 2003; Yu & Lee, 2008). A ΔE value less than 5.5, on the other hand, indicated a clinically acceptable colour difference whereas a ΔE value less than 2.6 indicated an ideal colour difference that could not be detected even by a clinician (Douglas & Brewer, 1998; Douglas *et al.,* 2007).

Few studies have investigated the effect of thickness and different abutment substrate on masking ability of monolithic zirconia (Tabatabaian, Taghizade *et al.*, 2018; Bayindir & Koseoglu, 2020; Ansarifard *et al.*, 2021; Elkhodary & Aboubakr, 2021; Kassim *et al.*, 2021). It has been demonstrated that increasing the thickness of zirconia reduces translucency and increases colour masking ability. It has also been demonstrated that abutment substrate affects the masking ability of zirconia restorations and can be predicted based on zirconia translucency (Oh & Kim, 2015; Tabatabaian *et al.*, 2016; Ansarifard *et al.*, 2021). However, the masking ability of different brands of monolithic zirconia restorations at various thicknesses has not been adequately investigated, particularly on darker abutment substrates. Thus, the objective of the present study was to determine the minimum thickness of monolithic zirconia required to achieve an acceptable masking ability and to examine how brand and abutment substrate influenced that masking ability. The hypothesis was that the masking ability of monolithic zirconia would be affected by the brand, thickness, and abutment substrate.

MATERIALS AND METHODS

Seventy-two A2-shade, monolithic zirconia disc specimens in three different thicknesses (1.0, 1.5 and 2.0 mm) were prepared from three commercially available brands (Table 1). Based on previous study results, the sample size was calculated using $\alpha = 0.05$ and $\beta = 0.4$ (Tabatabaian, Motamedi *et al.*, 2018). There were eight specimens in each thickness group. Autodesk® Fusion 360 software (Autodesk Inc, San Francisco, CA) was used to design the specimens, which were then milled on a milling machine (X-Mill 220, XTCERA, Shenzen, China). Prior to sintering, the disc was immersed for six seconds in a colouring liquid shade A2 (DD Bio ZX² monolithic zero LZDD; Dental Direkt GmbH, Spenge, Germany). The milled specimens were sintered in a high-temperature furnace according to the manufacturers' instructions (Ceramill Therm S, Amann Girrbach, Koblach, Austria). The thicknesses of the discs were measured using a digital micrometre (293 MDC-MX Lite; Mitutoyo Corp, Kanagawa, Japan). The discs were adjusted to the desired thicknesses within a ±0.02 mm range using an adjustment and polishing kit (ZILMaster, SHOFU, Kyoto, Japan). Each specimen was polished with a two-step diamond-impregnated silicone technique at 10,000 rpm, 60 strokes over 90 seconds, in wet slurry conditions. The discs were cleaned for 15 minutes in an ultrasonic bath of sterile water before they were dried.

As a control, a 10 mm cube of white acrylic (Perspex® Acrylic, PerspexSheet, Leicester, UK) was designed with Autodesk® Fusion 360 software and milled with X-Mill 220 milling machine. Three types of tested substrate (Table 2) were made with the same dimensions as the control (Fig. 1). They were resin composite made of Ceram.X® Duo shade D3, Ceram.X® Duo shade D4 (Denstply Sirona, Charlotte, NC) and semi-precious alloy of Argedent Bio 720PF (Argen Corporation, San Diego, CA). The materials for resin composite substrate were polymerised incrementally (5 layers of 2 mm thickness) for 40 seconds at 800 mW/cm². The semi-precious alloy substrate was created using burnout and casting techniques. Resin composite substrate was polished with silicon carbide abrasives of 800 grit, whereas semi-precious alloy substrate was polished with a metal polishing kit (Brownie Greenie Supergreenie, SHOFU, Kyoto, Japan). All substrates were cleaned and dried in an ultrasonic bath for 15 minutes before use.

Table 1 List of tested monolithic zirconia brands used in the present study

Material brand	Manufacturer	Light transmittance	Composition
Nacera® Pearl 1	DOCERAM Medical Ceramics GmbH, Dortmund, Germany	44%	$ZrO_2 + HfO_2 + Y_2O_3$, >99.0 wt%
DD cubeX²	Dental Direkt, Spenge, Germany	49%	$ZrO_2 + HfO_2 + Y_2O_3$, ≥99.0 wt%
XTCERA TT	XTCERA, Shenzen, China	55%	$ZrO_2 + HfO_2 + Y_2O_3$, >94.0 wt%

Table 2 List of tested abutment substrate materials used in the present study

Material brand	Manufacturer	CIELAB values	Composition
Ceram.X® Duo (D3-shade)	Dentsply Sirona	L^*= 57.51 a^*= 2.20 b^*= 13.26	Nano hybrid resin composite
Ceram.X® Duo (D4-shade)	Dentsply Sirona	L^*= 52.92 a^*= 3.60 b^*= 15.82	Nano hybrid resin composite
Argedent Bio 720PF	Argen Corporation	L^*= 77.35 a^*= 2.41 b^*= 18.80	Au (72%), Pt (13.9%), Ag (10.5%), Zn (3%), Nb (<1%), Mn (<1%) & Ir (<1%)

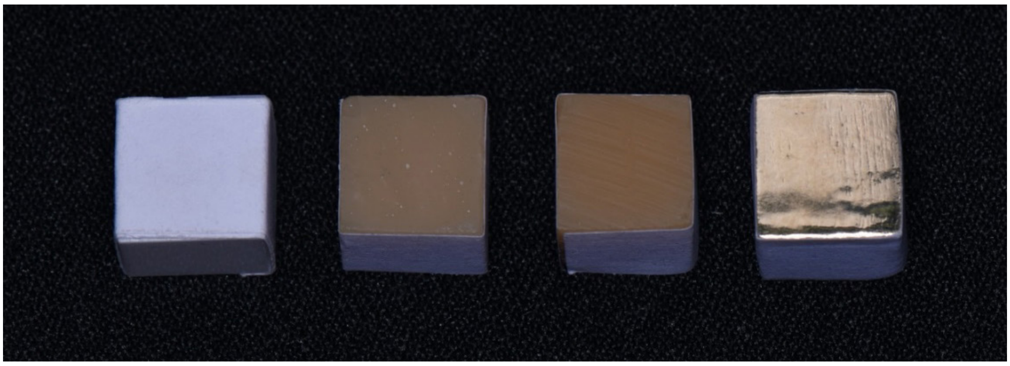

Fig. 1 Types of abutment substrate. From right, white acrylic (control), D3-shade resin composite block, D4-shade resin composite block and semi-precious metal alloy block.

Colour measurements were made using a spectrophotometer CM-5 (Konica Minolta Inc, Singapore). The substrates and tested discs were placed at the predetermined location in the centre of the mould. All specimens that will be placed on abutment substrates had their L^*, a^*, and b^* colour attributes measured. To determine colour differences between specimens on white and tested substrates, ΔE values were calculated. The measured ΔE values were then compared to thresholds for perceptible tolerance (2.6) and acceptable tolerance (5.5). Initially all three zirconia groups with various thicknesses were tested on the D4-shade composite resin substrate. Subsequently, another investigation was conducted on 72-disc specimens from the monolithic zirconia brand with the best masking ability on two other lighter shades: D3-shade resin composite and semi-precious alloy.

For data analysis, SPSS 23.0 software (SPSS Inc., Chicago, IL, USA) was used. The effects of thickness, brand and substrate and their interactions on colour differences (ΔE), were assessed using two-way ANOVA ($\alpha = 0.05$) with the Bonferroni correction.

RESULTS

Nacera® Pearl 1 at 1.5 mm thickness was adequate to achieve an acceptable tolerance threshold on a D4-shade resin composite substrate, whereas 2.0 mm of DD cubeX² and XTCERA TT were required. As for the perceptible tolerance threshold, only the 2.0 mm of Nacera® Pearl 1 could achieve it (Fig. 2).

Figure 3 illustrates the ΔE values for each thickness group of Nacera® Pearl 1 on various substrates that exceed the perceptible and acceptable tolerance thresholds. When ΔE values were compared to tolerance thresholds, all specimen groups except for the 1.0 mm thick on D3 and D4 resin composite substrates achieved an acceptable tolerance threshold. The perceptible tolerance threshold could only be met with a thickness of 2.0 mm for both shades of resin composite and 1.5 mm for semi-precious alloy substrate.

A two-way ANOVA was performed to analyse the effect of monolithic zirconia brand and thickness on E. There was a statistically significant interaction between types of monolithic zirconia brand and its thickness on E, $F(4,63) = 22.71$, $p < 0.001$. Simple main effects analysis showed that monolithic zirconia brand and thickness did have a statistically significant effect on E ($p < 0.001$) (Table 3). All pairwise comparisons were run for each simple main effect. It was conducted in two orders: between thicknesses in each monolithic zirconia brand (Order 1) and between monolithic zirconia brands in each thickness (Order 2). The results were statistically significant ($p < 0.001$) (Table 4).

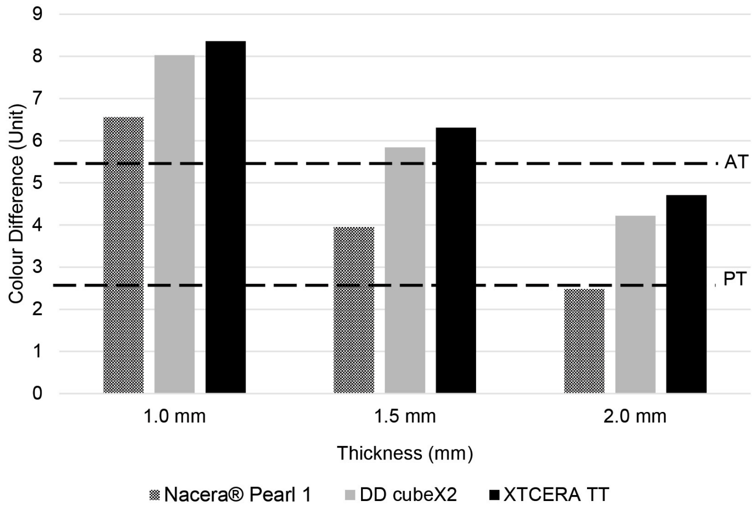

Fig. 2 Mean colour difference (E) of each thickness group of different types of monolithic zirconia in comparison with acceptable tolerance threshold (AT) and perceptible tolerance threshold (PT).

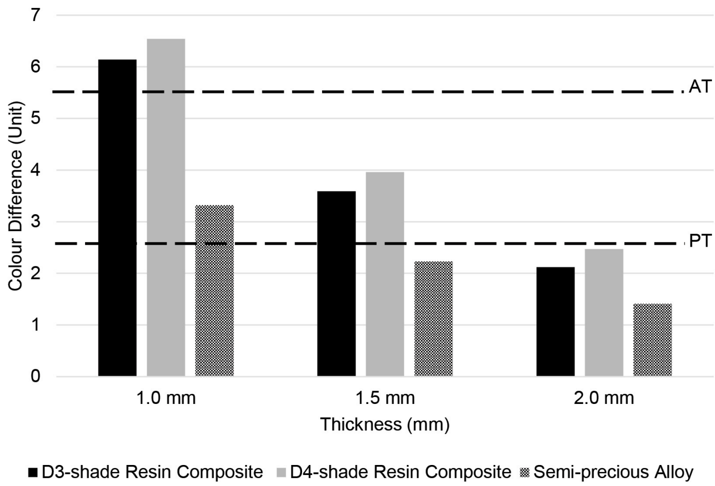

Fig. 3 Mean colour difference (E) of Nacera® Pearl 1 based on thickness and abutment shades tested comparison with acceptable tolerance threshold (AT) and perceptible tolerance threshold (PT).

Table 3 Results of two-way ANOVA on effects of monolithic zirconia brand and thickness on E

Source	Type III sum of squares	df	Mean square	F	*p*-value
Monolithic zirconia brand	60.100	2	30.050	3170.32	< 0.001
Thickness	177.970	2	88.980	9387.73	< 0.001
Interaction	0.861	4	0.220	22.71	< 0.001
Error	0.597	63	0.009		

Table 4 Results of pairwise comparisons. Order 1: between thickness in each type of monolithic zirconia brand; Order 2: between types of monolithic zirconia brand of each thickness

Order 1				
Monolithic zirconia brand	**Thickness (mm)**		**Mean difference (95% CI)**	***p*-value**
Nacera® Pearl 1	1.0	1.5	2.58 (2.46, 2.70)	< 0.001
		2.0	4.06 (3.94, 4.18)	< 0.001
	1.5	2.0	1.49 (1.37, 1.61)	< 0.001
DD cubeX²	1.0	1.5	2.29 (2.17, 2.41)	< 0.001
		2.0	3.87 (3.75, 3.99)	< 0.001
	1.5	2.0	1.58 (1.46, 1.70)	< 0.001
XTCERA TT	1.0	1.5	1.97 (1.85, 2.09)	< 0.001
		2.0	3.55 (3.43, 3.67)	< 0.001
	1.5	2.0	1.58 (1.56, 1.70)	< 0.001

Order 2				
Thickness (mm)	**Monolithic zirconia brand**		**Mean difference (95% CI)**	***p*-value**
1.0	NP1	DDCX	1.54 (1.66, 1.42)	< 0.001
		XTT	1.74 (1.86, 1.62)	< 0.001
	DDCX	XTT	0.20 (0.32, 0.08)	< 0.001
1.5	NP1	DDCX	1.83 (1.96, 1.71)	< 0.001
		XTT	2.34 (2.46, 2.22)	< 0.001
	DDCX	XTT	0.51 (0.63, 0.39)	< 0.001
2.0	NP1	DDCX	1.74 (1.86, 1.62)	< 0.001
		XTT	2.25 (2.37, 2.13)	< 0.001
	DDCX	XTT	0.51 (0.63, 0.39)	< 0.001

Note: Multiple comparisons, adjusted by Bonferroni. (NP1, Nacera® Pearl 1; DDCX, DD cubeX²; XTT, XTCERA TT).

A two-way ANOVA was performed to analyse the effect of abutment shade and thickness on E. There was a statistically significant interaction between thickness and abutment shade on E, $F(4,63) = 1572.78$, $p < 0.001$. Simple main effects analysis showed that abutment shade and thickness did have a statistically significant effect on E ($p < 0.001$) (Table 5). All pairwise comparisons were run for each simple main effect. It was conducted in two orders: between thicknesses in each abutment shade (Order 1) and between abutment shades in each thickness (Order 2). All tests showed statistically significant result ($p < 0.001$) (Table 6).

Table 5 Results of two-way ANOVA on effects of types of abutment substrate and thickness on E

Source	Type III sum of squares	df	Mean square	F	*p*-value
Abutment substrate	54.500	2	27.250	13401.89	< 0.001
Thickness	135.620	2	67.810	33353.23	< 0.001
Interaction	12.790	4	3.200	1572.78	< 0.001
Error	0.128	63	0.002		

Table 6 Results of pairwise comparisons. Order 1: between thickness in each type of abutment substrate; Order 2: between types of abutment substrate in each thickness

Order 1				
Types of abutment substrate	**Thickness (mm)**		**Mean different (95% CI)**	***p*-value**
D3-shade resin composite	1.0	1.5	2.56 (2.50, 2.61)	< 0.001
		2.0	4.02 (3.96, 4.07)	< 0.001
	1.5	2.0	1.46 (1.41,1.52)	< 0.001
D4-shade resin composite	1.0	1.5	2.58 (2.52, 2.63)	< 0.001
		2.0	4.06 (4.01, 4.12)	< 0.001
	1.5	2.0	1.49 (1.43, 1.54)	< 0.001
Semi-precious alloy	1.0	1.5	1.09 (1.04, 1.15)	< 0.001
		2.0	1.90 (1.85, 1.96)	< 0.001
	1.5	2.0	0.81 (0.76, 0.87)	< 0.001

Order 2				
Thickness (mm)	**Types of abutment substrate**		**Mean different (95% CI)**	***p*-value**
1.0	D3	D4	0.39 (0.45, 0.34)	< 0.001
		SPA	2.83 (2.77, 2.88)	< 0.001
	D4	SPA	3.22 (3.16, 3.27)	< 0.001
1.5	D3	D4	0.37 (0.43, 0.32)	< 0.001
		SPA	1.36 (1.31, 1.42)	< 0.001
	D4	SPA	1.73 (1.79, 1.68)	< 0.001
2.0	D3	D4	0.35 (0.40, 0.29)	< 0.001
		SPA	0.71 (0.66, 0.77)	< 0.001
	D4	SPA	1.06 (1.00, 1.11)	< 0.001

Note: Multiple comparisons, adjusted by Bonferroni. (D3, D3-shade resin composite; D4, D4-shade resin composite; SPA, Semi-precious alloy).

DISCUSSION

The present study determined the minimum thickness required for three different brands of A2 shade monolithic zirconia to achieve an acceptable and perceptible tolerance threshold on various abutment substrates. The findings of the present study demonstrated that brand, thickness of monolithic zirconia, and abutment substrate significantly influenced the value of ΔE. Hence, the hypothesis is accepted.

Nacera® Pearl 1 performed better than DD cubeX² and XTCERA TT in masking a D4-shade resin composite substrate at 1.5 mm thickness while the latter two were able to achieve adequate masking only at 2.0 mm thickness. When tested against a lighter shade of D3 and semi-precious alloy, Nacera® Pearl 1 needed a thickness of 1.5 mm and 1.0 mm, respectively to achieve the acceptable tolerance threshold and 2.0 mm and 1.5 mm, respectively for the perceptible tolerance threshold.

The brand of the monolithic ceramic has been shown to play a significant role in its masking ability as it relates to the manufacturing factors and hence the resultant translucency of the materials (Sulaiman *et al.*, 2015). The percentage of translucency is determined by the composition, grain size, sintering time protocol, and porosity of the monolithic zirconia (Vichi *et al.*, 2016). In the present study, the monolithic zirconia brand Nacera® Pearl 1 demonstrated the best masking ability due to its lower percentage of translucency (44%) when compared to DD cubeX² (49%) and XTCERA TT (55%). CopraSmile which has a translucency of 40% could mask the A4 shade of resin composite in a thickness of 0.9 mm (Tabatabaian, Motamedi *et al.*, 2018) and Kerox Dental Zirconia (49% translucency) in thicknesses of 0.6 mm, 1.1 mm and 1.5 mm could mask nickel chromium and zirconia, but not non-precious gold (Ansarifard *et al.*, 2021).

The present study demonstrates that increasing the thickness of monolithic zirconia restorations reduced ΔE values and improved the masking ability on each abutment substrate. This inverse relationship between thickness and translucency is independent of brand and polishing process (Sulaiman *et al.*, 2015). Harada *et al.* (2015) investigated the effect of thickness on translucency of newly introduced monolithic zirconia ceramics versus low translucency lithium disilicate ceramics at various thicknesses. To compare the specimens, the mean value of total transmittance of light determined by a spectrophotometer was used. It was discovered that as the thickness of the monolithic zirconia ceramic increased, the percentage of light transmittance decreased significantly. Church *et al.* (2017) investigated the translucency of four highly translucent monolithic zirconia ceramics of varying thicknesses (0.5 mm, 1.0 mm, 1.5 mm and 2.0 mm). The effect of ceramic material and thickness on translucency was significant.

The type of abutment substrate had a significant influence on the masking ability (ΔE) of translucent monolithic zirconia restoration and is in alignment with several reports (Suputtamongkol *et al.*, 2013; Oh & Kim, 2015). Semi-precious alloy showed a significantly lower ΔE values than the resin composite substrate which could be due to the higher L* values of semi-precious alloy which indicate a lighter colour measurement that is quite similar to the colour of natural dentine. As a result, masking the effect of a precious gold alloy colour background is less critical for a monolithic zirconia restoration. Hence, when a cast post is indicated in the clinical setting, a semi-precious, non-precious gold-coloured alloy and zirconia ceramic are preferred over a nickel-chromium alloy (Tabatabaian, Taghizade *et al.*, 2018). This can also be used when selecting the implant abutment in the anterior region. A gold-colored titanium abutment may be the best option for restoring an anterior implant-supported crown.

Tabatabaian, Motamedi *et al.* (2018) demonstrated that A4-shade resin composite substrate could be masked by a 0.9 mm thick monolithic zirconia to achieve the final color of an A2 shade. In the present study, D4 and D3 resin composite shades could only be masked by mostly 2.0 mm monolithic zirconia restorations. These contradictory results could be due to the difference in CIELAB (L*, a*, and b*) values between the various shades of the resin composite substrate. The A4-shade resin composite showed the lightest CIELAB values (L* =

67.0, $a^* = 3.6$, $b^* = 26.0$) as compared to D3-shade ($L^* = 57.51$, $a^* = 2.2$, $b^* = 13.26$) and D4-shade resin composite ($L^* = 52.92$, $a^* = 3.6$, $b^* = 15.82$) substrates.

The present study, however, has several limitations. First, the results are restricted to three brands of monolithic zirconia ceramic with an A2 shade. The A2 shade was chosen because it is the most commonly used shade clinically, but it will be useful to evaluate the darker shade zirconia. The effect of luting cement on the masking ability of monolithic zirconia ceramics was also not evaluated in the present study. More research is needed to determine how luting cements and shades of monolithic zirconia affect its masking ability.

CONCLUSION

Within the limitations of this in vitro study, the following conclusions could be drawn. All three factors, zirconia brand, thickness, and abutment substrate, had an effect on the ΔE ($p < 0.001$). Nacera® Pearl 1 had the best masking ability, with an acceptable tolerance threshold of 1.5 mm for D3- and D4- shade resin composite and 1.0 mm for semi-precious alloy and a perceptible tolerance threshold of 2.0 mm for D3- and D4- shade resin composite and 1.5 mm for semi-precious alloy substrates.

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