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Masking Ability of Translucent Monolithic Zirconia Ceramic: The Effect of Thickness

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Abstract

The minimum thickness required of monolithic zirconia restorations to achieve sufficient masking ability for optimal aesthetics is unclear. Hence, this study investigates the minimum thickness required to achieve acceptable and perceptible tolerance thresholds by testing monolithic zirconia discs in various thicknesses from 0.4-2.0 mm on a D4 shade substrate using spectrophotometry. Delta-E (ΔE) was calculated and compared with the established acceptable (ΔE = 5.5) and perceptible (ΔE = 2.6) tolerance thresholds. There was a significant negative correlation between thickness and ΔE ($R^2 = 0.952$, $p < 0.001$). The mean ΔE decreases from 13.43 (±0.34) to 3.07 (±0.03) as thickness increases from 0.4 to 2.0 mm. Significant differences in ΔE were detected when there was at least a 0.4 mm difference in thickness between the groups. An acceptable tolerance threshold was achieved with a minimum thickness of 1.4 mm, but the perceptible tolerance threshold was unachievable even at the maximum thickness of 2.0 mm. In conclusion, the masking ability of translucent monolithic zirconia reduces with decreasing thickness, and a minimum thickness of 1.4 mm is recommended for the acceptable masking ability of a dark substrate.

Disciplinary: Dentistry (Dental Materials, Prosthodontics, Restorative Dentistry, Dental Engineering).

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1 Introduction

Translucent monolithic zirconia crowns were developed to solve porcelain chipping associated with veneered zirconia crowns by eliminating the use of copings underneath the crowns (Marchack et al., 2011). Monolithic zirconia was shown to have excellent mechanical properties (Sulaiman et al., 2016; Vichi et al., 2016; Zhang et al., 2016) acceptable biocompatibility (Bremer et al., 2011) improved tooth-colour matching (Tabatabaian et al., 2018), and costs less compared to precious metal alloys (Conrad et al., 2007). However, the elimination of copings compromises the aesthetic outcome of the monolithic crowns when used over a dark coloured substrate of metal post and core, titanium implant abutment, and severely discoloured tooth (Kim & Kim, 2016; Kurbad, 2016). The use of opaque luting cement is ineffective to mask the severe discolouration and may compromise the final colour of the crowns (Malkondu et al., 2016). The masking ability of zirconia restorations is influenced by intrinsic factors such as the level of translucency (Wang et al., 2013), thickness (Wang et al., 2013; Kumagai et al., 2013; Tabatabaian et al., 2019), and the type of the zirconia material (Wang et al., 2013; Oh & Kim, 2015; Tuncel et al., 2016). There are also extrinsic factors which are the shade of the underlying substrate (Basso et al., 2017; Choi & Razzoog, 2013; Suputtamongkol et al., 2013) and the type of luting cement used (Malkondu et al., 2016; Kurbad, 2016). Among these factors, translucency and thickness play major parts in controlling the ultimate colour of the restoration.

The translucency of monolithic zirconia correlates negatively with the thickness (Wang et al., 2013; Harada et al., 2015; Kwon et al., 2018; Tabatabaian et al., 2017). Thus, increasing the thickness will reduce translucency and increase its masking ability. The translucency parameter (TP) for translucent zirconia materials ranges from 11.2 to 15.3 which is less than the TP value for lithium disilicate (16.89) (Conrad et al., 2007; Kwon et al., 2018). Due to this advantage of partial translucency, thinner restorations made from monolithic zirconia may result in greater masking ability over the dark substrates as compared with other glass-ceramic materials, and this will lead to more conservative tooth preparation. However, conclusive data on the minimum thickness required for the masking ability of this material is scarce since previous studies have mainly focused on the masking ability of the traditional zirconia as coping materials (Oh & Kim, 2015; Choi & Razzoog, 2013; Tabatabaian et al., 2017; Tabatabaian et al., 2018). Tabatabaian et al. (2019) reported that the minimum possible thickness of 1 and 1.6 mm of zirconia coping is required to mask the substrate to achieve acceptable tolerance and perceptible tolerance threshold respectively. Apart from that, zirconia coping has to be veneered with feldspathic ceramic which increases the risk of chipping. In addition, it requires considerable tooth preparation to accommodate the full thickness of the restoration. In contrast, monolithic zirconia by itself is constructed as a final restoration without the need for such coping underneath it. Thus, the challenge is to establish the minimum thickness of translucent monolithic zirconia required to ensure adequate masking ability while keeping the tooth preparation as conservative as possible.

Besides, previous findings may not apply to monolithic zirconia as their translucency parameter is higher (14.05) than coping zirconia (11.48) (Vichi et al., 2016).

Hence, this study aimed to determine the minimum thickness needed to achieve perceptible and acceptable tolerances for colour differences or shade mismatch on a dark substrate. The relationship between the material thickness and color differences was also investigated. A wide range of monolithic zirconia thickness was constructed from 0.4 to 2.0 mm and their masking ability was measured over a D4 composite substrate by using the ΔE colour difference of the CIE (Commission Internationale de l'Éclairage) Lab colour system (Douglas & Brewer 1998; Douglas et al., 2007). The ΔE value obtained would be compared with a perceptible tolerance (2.6) and acceptable tolerance (5.5) threshold that has been suggested by Douglas et al. (2007). Perceptible tolerance threshold is the limit value at which 50% of the clinician could perceive a colour difference while acceptable tolerance threshold is the limit value at which 50% of the clinician would replace the ceramic crowns because of colour mismatch (Douglas et al., 2007; Paravina et al., 2019). It was hypothesised that the thicker the translucent monolithic zirconia ceramic, the lesser would be the ΔE colour difference detected from the dark substrate and this would improve its masking ability. The findings will be used as baseline data for future research and clinical application whenever translucent monolithic zirconia is used as the final restoration especially in the aesthetic zone.

2 Method

A total of 27 square-shaped monolithic zirconia specimens (1 cm x 1 cm) of 9 different thicknesses (0.4, 0.6, 0.8, 1, 1.2, 1.4, 1.6, 1.8, and 2 mm) were fabricated to represent various thicknesses of clinically possible monolithic zirconia restorations, ranging from veneers to complete coverage crowns and also based on a previous study by Tabatabaian et al. (2017). The specimens were fabricated from pre-shaded (A2) translucent monolithic zirconia ceramic blocks (inCoris TZI C, Dentsply Sirona) and sectioned into specified thicknesses using a linear precision saw (IsoMet 4000). The sectioned specimens were sintered in a high-temperature furnace according to the manufacturers' instructions (Ceramill Therm S, Amann Girrbach). The sintered specimens were subsequently trimmed and polished with a 3-step diamond-impregnated silicone polishing burs (ZILMaster, SHOFU) to achieve the planned thicknesses (± 0.02 mm) as measured by a micrometer (293 MDC-MX Lite; Mitutoyo Corp). The specimens were then cleansed in an ultrasonic bath of distilled water for 20 minutes and dried.

Two substrates were prepared, a 10 mm cube of white acrylic (to serve as control) and a dark D4 shade resin-based composite (Ceram X Duo - Dentine, Dentsply Sirona) by using a mould. The composite resin was polymerized incrementally (5 layers of 2mm thickness) for 40 seconds at 800 mW/cm^2. Both substrates were polished with silicon carbide abrasive paper of 800 grit and cleansed in an ultrasonic bath of distilled water for 20 minutes and dried.

For colour measurement, the monolithic zirconia specimen was placed directly on top of the substrate and positioned on the mouthpiece of a spectrophotometer (CM-5, Konica Minolta, Singapore). A white acrylic jig was used to ensure a consistent central position of the specimens and substrates on the mouthpiece and to exclude external light. The L^*(lightness or darkness coordinate), a^* (red-green chromaticity coordinate), and b^* (yellow-blue chromaticity coordinate) colour attributes were measured twice for each specimen and once on each substrate.

The device was calibrated per the manufacturer's instructions before each measurement was made. The ΔE was calculated by the device compare option to establish the colour difference of the specimen between the two substrates according to Equation (1), where W is White acrylic substrate and D is D4 shade composite resin substrate.

$$\Delta E^*_{WD} = [(L^*_W - L^*_D)^2 + (a^*_W - a^*_D)^2 + (b^*_W - b^*_D)^2]^{1/2} \quad (1),$$

The measured ΔE values were then compared with perceptible tolerance (2.6) and acceptable tolerance (5.5) thresholds.

ANOVA and Dunnet's post hoc tests were used for data analysis in SPSS 21 programme. Prior to data analysis with ANOVA, Kolmogorov-Smirnov test was used to ensure the data conformity to normal distribution, and all the assumptions of homogeneity of variances are met. The level of significance, p was set at < 0.05.

3 Result and Discussion

The mean ΔE values were found to be progressively decreasing from the highest of 13.43 (±0.34) to the lowest of 3.07 (±0.03) as the thickness of the zirconia specimen increases from 0.4 to 2.0 mm (Figure 1).

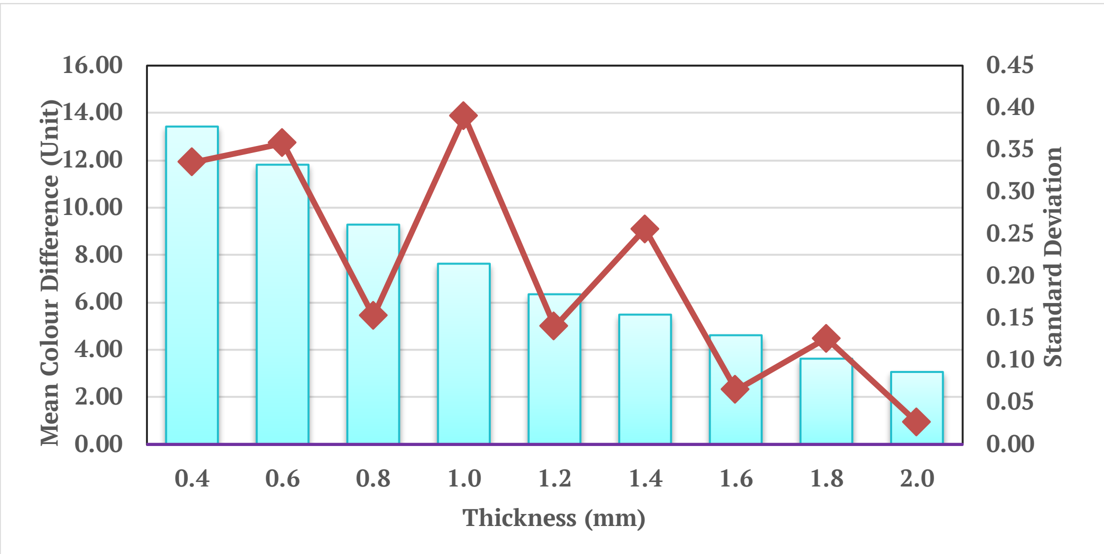

Figure 1: The mean colour difference (ΔE values) of each thickness of monolithic zirconia specimens.

ANOVA revealed that there were significant mean differences between the groups ($p<0.001$) and Dunnet's post hoc test showed that the mean difference between the groups was significant when there was a difference of at least 0.4 mm in thickness between the groups (Table 1). An acceptable tolerance threshold was achieved with a minimum thickness of 1.4 mm, but the perceptible threshold could not be achieved even with a thickness of 2.0 mm.

Table 1: Multiple Comparison of Mean Colour Difference Among Different Monolithic Zirconia Thickness.

Thickness (mm)	N	Mean	SD
0.4	3	13.43[a]	0.34
0.6	3	11.82[a]	0.36
0.8	3	9.29[b]	0.15
1.0	3	7.64[bc]	0.39
1.2	3	6.35[cd]	0.14
1.4	3	5.49[de]	0.26
1.6	3	4.62[e]	0.07
1.8	3	3.63[f]	0.13
2.0	3	3.07[f]	0.03

*Mean with a similar superscript letter indicates no significant difference (*p*>0.05) from each group based on multiple comparison Dunnett's Test analysis.

There was also a significant inversely proportional relationship between thickness and ΔE value (R2 = 0.952, p < 0.001) (Figure 2).

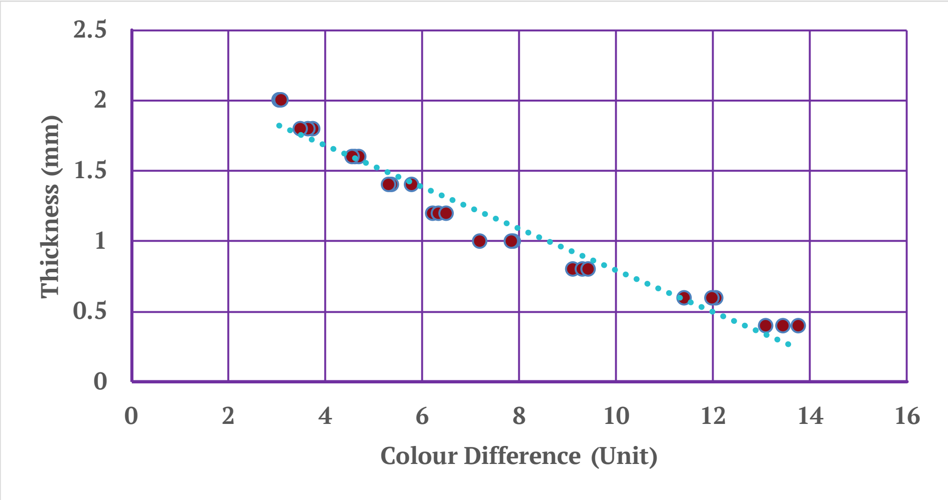

Figure 2: Negative linear relation between monolithic zirconia thickness and colour difference (ΔE values).

The present study investigated the effect of the thickness of translucent monolithic zirconia on its masking ability. The findings demonstrated that when the thickness of the monolithic zirconia ceramic increased, the value of ΔE decreased, thus increasing its masking ability. Hence, the hypothesis is accepted. The thickness of the translucent monolithic zirconia is found to correlate significantly with ΔE. When ΔE value is compared with the perceptible tolerance threshold (<2.6) none of the specimens qualified, meaning all colour differences of each specimen can be perceived by most clinicians. When compared against acceptable tolerance threshold (<5.5) only zirconia thickness of 1.4 mm and above succeeded to mask D4 shade composite resin substrate with a clinically acceptable colour mismatch. D4 shade was chosen as the substrate to be masked as it represents the most severe form of discoloration that has been quantified. The result of this study, however, should be interpreted with caution as merely one brand of monolithic zirconia was investigated and the number of specimens per group was small (n-3). Nevertheless, the result obtained could be useful for further testing of the masking ability of different brands of monolithic zirconia.

Thicker zirconia imparts the masking effect due to the reduced amount of light that can be transmitted across the material. The greater the thickness, the lesser would be the translucency and the better the masking ability as exhibited in our study. A study by Sulaiman et al. (2015) also showed that translucency has an inverse relationship with the thickness of monolithic zirconia. The translucency of monolithic zirconia is closest to that of enamel and dentine when its thickness is less than 1 mm. They also found that the translucency is brand dependent and that partially stabilized zirconia is less translucent than a fully stabilized zirconia. Tabatabaian et al. (2018) investigated the masking ability of 2 brands of monolithic zirconia [DD cubeX^2 (Dental Direkt GmbH) and CopraSmile (Whitepeaks Dental Solutions GmbH & Co. KG)] and found that the minimum thickness to gain the acceptable masking ability of the colour difference between A2 and A4 substrate was 0.9 mm for both brands. The minimal thickness reported which is far less than the current study of 1.4 mm could be the result of dissimilar degrees of intensity of the colour differences measured. In the current study, the colour difference was measured between white and D4 shade substrate which was more intense compared to between A2 and A4. In a separate study, Tabatabaian et al. (2018) evaluated the effect of thickness on the zirconia core material. They concluded that the acceptable and perceptible masking ability was achieved with the minimum thickness of 1 and 1.6 mm respectively. In the present study, thicker specimens of 1.4 mm were required to achieve the acceptable clinical masking ability, and the thickest specimen of 2.0 mm, did not meet the perceptible masking ability tolerance threshold. This could be explained by the opaquer characteristic of zirconia core material used in their study compared with our monolithic zirconia ceramic, which is partially translucent in nature.

A minimum thickness of 0.5 mm for monolithic zirconia restoration has been recommended for fracture resistance (Nakamura et al., 2015), but for a severely discoloured tooth with a D4 shade as used in the present study, the thickness may be increased to 1.4 mm. As such, a more aggressive tooth reduction is required to provide space for the zirconia without over countouring the restoration. However, this thicker requirement of monolithic zirconia to achieve optimum aesthetic could be offset by the use of luting cement (Malkondu et al., 2016). Malkondu et al. (2016) used 3 types of cement (glass ionomer, resin-modified glass ionomer, and resin cement) on 2 different thicknesses of monolithic zirconia to evaluate the perceptibility and acceptability of the monolithic zirconia-cement combinations. There was a significant increase in translucency as the zirconia thickness decreased from 1.0 to 0.6 mm. The influence of the luting cement on the colour also increased as the thickness decreased. The colour differences caused by the luting cement were within the acceptable tolerance threshold ($\Delta E<5.5$), except for resin cement at 0.6 mm thickness. Bayindir and Koseoglu (2020) showed that the use of opaque cement resulted in a clinically incompatible colour change ($\Delta E>3.7$) of the zirconia specimens of varying thicknesses from 0.5-2.0 mm.

This study tested on one ceramic brand that was divided into 9 groups with varying thicknesses from 0.4-2.0 mm. Although the number of specimens used for each group was small (n=3), significant differences in ΔE could be detected when there was at least a 0.4 mm difference in thickness between the groups. The result shows that a minimum thickness of 1.4 mm is required for acceptable masking ability, a baseline thickness of 1.0 mm is recommended for future studies to exhibit significant colour changes required on the masking ability of different types of monolithic zirconia on a dark substrate. However, if the masking ability of monolithic zirconia were to be tested in combination with luting cement, reduced thickness is possible.

4 Conclusion

Within the limits of this in-vitro study, it may be concluded that a 1.4 mm thickness of monolithic zirconia (inCoris TZI C, Dentsply Sirona) provides an acceptable clinical masking ability against a dark substrate. The masking ability of translucent monolithic zirconia is reduced with decreasing thickness. A minimum thickness of 1.0 mm is recommended as a baseline thickness for future studies investigating the masking ability of various types of monolithic zirconia on different shades of the dark substrate.

5 Availability of Data And Material

Data can be made available by contacting the corresponding author.

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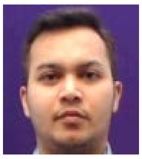

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