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Original article

Effects of abutment tooth and luting agent colors on final color of high-translucent zirconia crowns

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Abstract

Purpose: This study aimed to evaluate the effects of the tooth portion evaluated and the colors of the abutment tooth and resin luting agent on the final color of monolithic zirconia crowns.

Methods: Monolithic zirconia crowns were fabricated for left maxillary central incisors using two shades (A2 and A3) of highly translucent monolithic zirconia disks. A model of the abutment tooth was fabricated using resin core materials (white: W; dentin: D). The color of the crowns was measured with try-in pastes (clear: C; brown: B) as a resin-luting agent substitute. The measurement was performed after placing the crown on the model with the attached abutment tooth with try-in paste. The color of three labial portions (cervical, body, and incisal) was evaluated using a dental spectrophotometer. The color difference (ΔE) between the CIELab values of the zirconia disks and the final measurement of zirconia crowns was calculated.

Results: The ΔE between the crown of the A2 shade and the zirconia disk of the A2 shade had the highest ΔE value in the body portion with W-B (ΔE=3.92). Similarly, the A3 shade had the highest ΔE value in the cervical portion, with W-B (ΔE=4.27). The results of three-way ANOVA showed that the ΔE values were influenced by the tooth portion evaluated and the color of the abutment tooth.

Conclusions: The final color of the monolithic zirconia crowns was significantly influenced by the tooth portion evaluated and the color of the abutment tooth.

Keywords: *Y-TZP, CAD/CAM, Dental spectrophotometer, Shade, Esthetic dentistry*

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1. Introduction

Zirconia ceramics have excellent mechanical properties, including flexural strength and fracture toughness. With the development of computer-aided design and computer-aided manufacturing (CAD/CAM) technology, zirconia ceramics have become indispensable for prosthetic dental treatment [1]. Zirconia restorations with porcelain veneers have a good long-term clinical prognosis and are a popular treatment option in esthetic and prosthetic dentistry [2, 3]. In recent years, the advent of highly translucent 3 mol% tetragonal zirconia polycrystal (3Y-TZP), which reduces the alumina content and light-scattering properties of zirconia and improves its translucency, has enabled the use of monolithic zirconia crowns for prosthetic rehabilitation of molars [1]. Monolithic zirconia restorations have high biocompatibility and a nonporous structure, and their abrasion resistance is close to that of natural teeth [4, 5]. They cause significantly less abrasion of the antagonist teeth compared to porcelain-veneered zirconia crowns [5-7]. Monolithic zirconia restorations require less tooth preparation, reduce the clinical and laboratory times for fabrication, and chipping of porcelain can be avoided as veneering porcelain is not used. Recent improvements in the translucency of zirconia have made it possible to extend the scope of its application to the anterior teeth as a single-layered structure without veneering porcelain. The success and survival rates of monolithic zirconia crowns have been reported to be as high as 90% in clinical follow-ups of more than 3.5 years, making monolithic zirconia crowns an effective fixed dental prosthetic treatment option [8, 9]. Further developments include a higher yttria content to produce partially stabilized zirconia (PSZ), 4 mol% PSZ (4Y-PSZ), or 5 mol% PSZ (5Y-PSZ), which have more cubic crystals in the crystal phase. The translucency of monolithic zirconia crowns has improved, making it possible to use them for anterior teeth [1]. However, the increased transparency causes the colors of the abutment tooth and resin luting agent to significantly influence the final color of the prosthesis. Therefore, the selection and reproducibility of colors for highly transparent materials are challenging.

Tooth color selection is a critical issue in esthetic dentistry, and reliable sharing of tooth color information can facilitate successful treatment. However, in practice, it is challenging to perform [10, 11]. Achieving an appropriate color match between the natural dentition and prostheses necessitates a complex process involving two specific procedures: color selection and color reproduction. The first step is to select the most adaptable color for a prosthesis, which is chosen according to the shade of the adjacent teeth and prosthesis using dental shade guides and/or digital shade-measuring devices. The second step is to reproduce the selected shade using appropriate dental materials and techniques [11-13]. The most common method for color selection is to use a shade guide to visually select colors; however, it is not scientific; therefore, it is one of the least reliable processes in esthetic and prosthetic dentistry [14].

In 1976 and 1978, the Commission International del'Eclairage (CIE) L*a*b* (CIELab) color space system was proposed [15], in which, for the

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first time, it was possible to express color using numbers and calculate the difference between two colors in a manner corresponding to visual perception. In this system, which is regarded as the benchmark for scientific purposes, color is expressed using three coordinates: the L* value (lightness or darkness) coordinate and its range from 0 (black) to 100 (white), a* value, and b* value. The other a*b* are chromaticity coordinates, and the a* value is a measure of redness (positive a*) or greenness (negative a*). The b* value is a measure of yellowness (positive b*) or blueness (negative b*) [16]. The CIELab system is scientific and is useful for calculating color differences (ΔE), which can be used to compare the differences between the respective coordinate values for each object.

The high translucency of zirconia ceramics allows more light to enter and scatter [17-19], which means that the colors of the underlying abutment tooth and resin luting agent can significantly influence the final color of the zirconia restoration. However, there is little information regarding the influence of the color of the abutment teeth and the resin luting agent on the final color of highly translucent monolithic zirconia crowns. Therefore, the purpose of this study was to evaluate the effects of the tooth portion evaluated and the colors of the abutment teeth and resin luting agent on the final color of monolithic zirconia crowns.

2. Materials and methods

2.1. Fabrication of crowns

A ceramic crown with a deep chamfer of 0.8 mm was prepared on an artificial left maxillary central incisor (A55A-211; Nisshin, Kyoto, Japan) using diamond points (102R and SF102R; Shofu, Kyoto, Japan) in accordance with the standard protocol used in clinical practice [20]. Impressions of the abutment were taken using silicone impression material (Examixfine Regular; GC, Tokyo, Japan) with a cylindrical mold and resin core build-up materials (Clearfil DC Core Automix ONE; Kuraray Noritake Dental, Tokyo, Japan) (Table 1) were used to fabricate the abutment tooth model. The abutment tooth models were prepared in white (W) and dentin (D) (Fig. 1–1). Monolithic zirconia crowns were fabricated using two shades of highly translucent monolithic zirconia disks (A2 and A3, Ceramill Zolid HT+ PS, Amann Girrbach, Koblach, Austria) using CAD/CAM system (Ceramill DNA Generation, Amann Girrbach). The maxillary model (500A, Nisshin) with the attached abutment tooth model was scanned using a fully automatic 2-axis light stripe projection method scanner (Ceramill Map400, Amann Girrbach). Based on the scan data, the crown was designed using CAD software (Ceramill Mind; Amann Girrbach) by mirroring the contralateral tooth. The cement space was set to 50 μm, which is the standard setting. The designed crown was fabricated using a CAM machine (Ceramill Motion 2, Amann Girrbach). The fabricated crowns were sintered at a maximum temperature of 1520 °C for 12 h in a sintering furnace (Ceramill Therm 3, Amann Girrbach) according to the sintering schedule recommended by the manufacturer. The crowns were then polished using rubber polishing burs (Zircoshine HP, Shofu Inc., Kyoto, Japan) and glazing paste (Super Star V, Nippon ShikaKogyosha, Tokyo, Japan) by the same dental technician. Eight specimens were prepared for each shade, with a total of 16 specimens (Fig. 1–2).

2.2. Spectrophotometric analysis

A try-in paste plays an important role in envisaging the final color of the crown by simulating the color effect produced by the completely polymerized resin luting agent after light activation. Therefore, try-in pastes based on glycerin gel of two colors (Panavia V5 try-in paste clear (C) and brown (B), Kuraray Noritake Dental) were used as resin luting agent substitutes (Fig. 1–3). The final color generated by the combination of abutment teeth, try-in paste, and crown was measured in a dark box (Fig. 1–4). The non-contact type of dental spectrophotometer (Crystaleye; Olympus, Tokyo, Japan) was calibrated according to the manufacturer's instructions before each measurement. Three labial portions (cervical, body, and incisal) of the labial surface of the crown were evaluated three times each, and the average L*, a*, and b* values were recorded (Fig. 1–5). The chroma (C*) values were calculated using the following formula: $C^* = [(a^*)^2 + (b^*)^2]^{1/2}$. The color difference (ΔE) was calculated based on the CIELab values of the zirconia disk and the final color of the zirconia crown. ΔE was calculated using the following formula: $\Delta E = [(L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2]^{1/2}$. To obtain the thickness of the crown at each evaluated portion, a polymethyl methacrylate (PMMA) crown was duplicated using the CAD data, and the thickness of the labio-lingual cross-section of the central part was measured (Fig. 1–5). Table 2 shows the CIELab values for the zirconia disks used in this study. The L*, a*, and b* values were calculated for the prepared zirconia cubes (10 × 10 × 10 mm) of A2 and A3 shades and used as reference values. Two types of abutment tooth colors and resin luting agent substitute colors were evaluated at the three defined labial portions for each crown.

2.3. Statistical analyses

Levene's tests were performed to evaluate the normality and homogeneity of variance. A three-way ANOVA was used to assess the effects of the measurement portion, the colors of the abutment tooth and the resin luting agent substitute, and their interaction with the ΔE values.

Table 1. Materials used in this study.

Material		Manufacturer	Lot no.
Ceramill Zolid HT+ PS	A2	Amann Girrbach	1809000
	A3		1808000
Clearfil DC Core Automix ONE	White	Kuraray Noritake Dental	4D0182
	Dentin		580293
Panavia V5 try-in paste	Clear	Kuraray Noritake Dental	6J0022
	Brown		5F0017

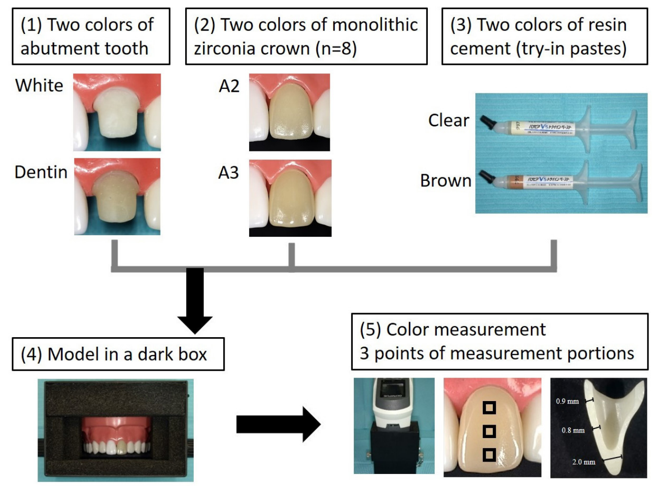

Fig. 1. Experimental procedure. (1) Different color of resin core build-up materials to fabricate the abutment models (White, Dentin), (2) Monolithic zirconia crowns were fabricated with two colors of highly translucent monolithic zirconia disks, (3) Two colors of try-in paste as resin luting agent substitute, (4) The maxillary model containing the crown on abutment teeth with try-in paste was seated in a dark box for measurement, (5) The crowns of three labial surfaces (cervical, body, and incisal) were measured. The thickness of the duplicate PMMA crown was used as a guide for measurement of thickness.

Table 2. Reference of the CIELab values of the zirconia disks.

Zirconia disk	L*	a*	b*
A2	67.11	4.52	18.88
A3	65.85	5.13	19.64

Tukey's HSD test was used as a post-hoc test to assess the effect of ΔE values within each group (α=0.05) (JMP Pro 15.1.0; SAS Institute, Cary, NC, USA).

3. Results

The L*-C* distribution map of the final colors of the monolithic zirconia crowns of shades A2 and A3 are shown in Figures 2–4 for each tooth portion evaluated. With crowns of the A2 shade, the L* value was in the range of 65.5 to 69.1, and the C* value ranged from 17.7 to 20.7 in the cervical portion. Similarly, in the body portion, the L* value ranged from 67.7 to 70.6, and the C* value ranged from 18.4 to 20.6. In the incisal portion, the L* value ranged from 67.8 to 68.4, and the C* value ranged from 16.5 to 17.5. Further, with the crowns of shade A3, the L* value ranged from 64.2 to 68.1, and the C* value ranged from 20.2 to 23.5 in the cervical portion. Similarly, in the body portion, the L* value ranged from 65.4 to 68.2, and the C* value ranged from 19.7 to 22.4. In the incisal portion, the L* value ranged from 64.7 to 66.0, and the C* value ranged from 18.0 to 18.8. For crowns of both shades, A2 and A3, with the same abutment tooth color, the L*-C* distribution tended to be similar regardless of the measurement points, or the difference in the resin luting agent substitutes color. Furthermore, in the incisal portions, the final colors of the crowns of both shades, A2 and A3, showed little difference in the L* value as compared to the zirconia disks, but the C* value tended to decrease.

The color difference between the crown of the A2 shade and the zirconia disk of the A2 shade had the highest ΔE value in the body portion with W-B (ΔE=3.92) and the lowest value in the body portion with D-B (ΔE=1.40) (Table 3). Similarly, the color difference between the A3 shade crown and the A3 shade zirconia disk had the highest ΔE value in the cervical portion with W-B (ΔE=4.27) and the lowest value in the body portion with D-C (ΔE=1.39) (Table 4).

The results of three-way ANOVA showed that the ΔE values were influenced by the tooth portion evaluated and the color of the abutment tooth, but not by the color of the try-in paste (Table 5). Significant differences in the ΔE values were also found among the different measurement portions and abutment teeth in the group (Table 6).

4. Discussion

This study evaluated the effects of the colors of abutment teeth and resin luting agents on the final color of monolithic zirconia crowns. The final shade of the monolithic zirconia crown was found to be dependent on the tooth portion evaluated and the color of the abutment tooth when compared to the shade of the disk used to fabricate the crown.

Johnston et al. interpreted the color differences clinically by classifying acceptable values. For 0.5 mm composite resin veneer restorations, the average color difference between the teeth considered to be matching in the oral environment had a ΔE value of 3.7 [21]. Later, it was discovered that one single value was probably not sufficient to compare the colors, and the differentiation between perceptibility (the difference that can be identified by the human eyes) and acceptability (the difference that is considered tolerable) was proposed [11]. Douglas et al. found that the predicted difference at which 50% of dentists could perceive a color difference (50/50 perceptibility) for denture teeth had a ΔE value of 2.6, and the predicted difference at which 50% of the prosthesis would be remade due to a clinically unacceptable color match had a ΔE value of 5.5 [22]. Further, it has been reported that the CIELab 50/50 perceptibility threshold of monochromatic ceramic specimens has a ΔE value between 1.2 and 1.7, whereas the 50/50 acceptability threshold has a ΔE value between 2.7 and 3.5 [23, 24]. Vichi et al. demonstrated the use of three different intervals to distinguish color differences. ΔE values less than 1.0 indicated no perceptible difference in the colors of the human eye. ΔE values larger than 1 and smaller than 3.3 indicated an appreciable difference as judged by skilled operators but clinically acceptable color matching, and ΔE values larger than 3.3 indicated perceivable differences as judged by unskilled observers [25]. Despite several studies, the identification of ΔE values to differentiate between perceptibility and acceptability is challenging, and there is no consensus yet on an acceptable limit. However, the W-C body

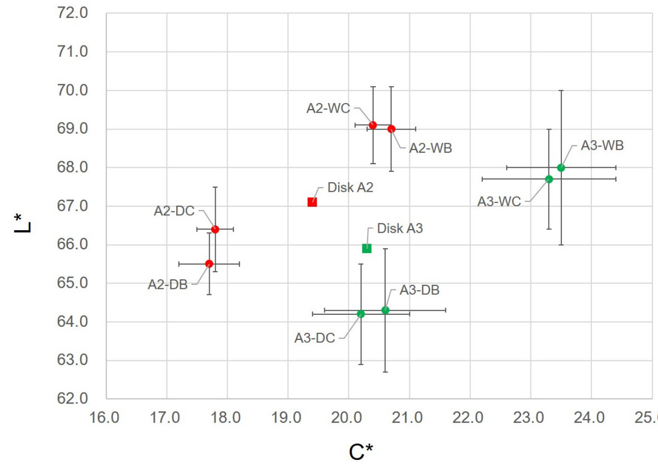

Fig. 2. L*-C* distribution for the cervical portion of monolithic zirconia crowns of A2 and A3 shades.

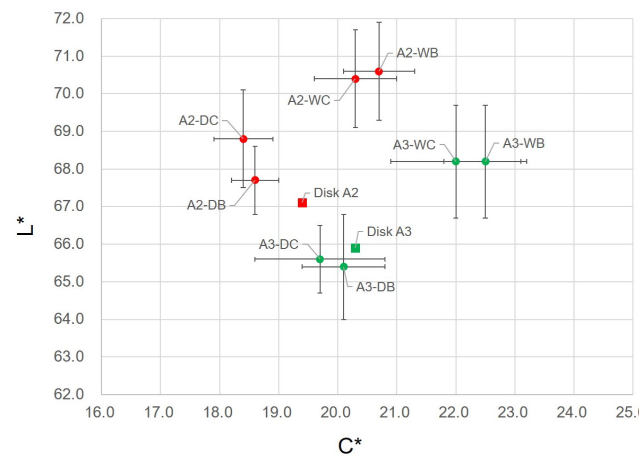

Fig. 3. L*-C* distribution for the body portion of monolithic zirconia crowns of A2 and A3 shades.

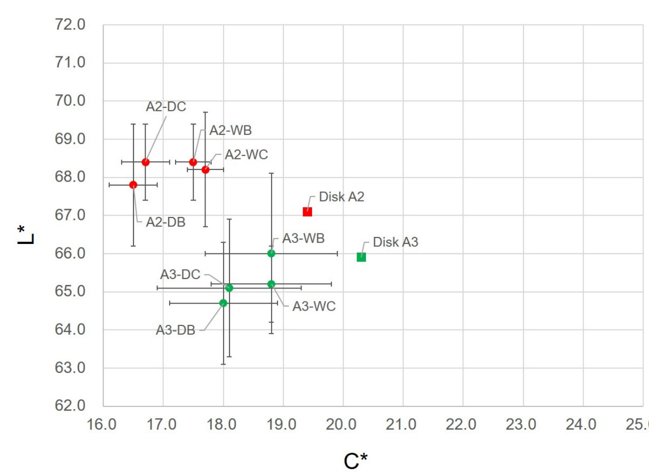

Fig. 4. L*-C* distribution for the incisal portion of monolithic zirconia crowns of A2 and A3 shades.

Table 3. Mean and standard deviation values of color difference (ΔE) between final color of monolithic zirconia crowns and A2 shade of zirconia disk (n=8).

Crown shade	Resin core	Resin luting agent (Try-in paste)	Measurement portion	Color difference (ΔE)
A2	White	Clear	Cervical	2.36 ± 0.78
		Brown		2.45 ± 0.73
	Dentin	Clear		1.95 ± 0.67
		Brown		2.41 ± 0.69
	White	Clear	Body	3.80 ± 1.13
		Brown		3.92 ± 1.00
	Dentin	Clear		2.41 ± 0.90
		Brown		1.40 ± 0.60
	White	Clear	Incisal	2.70 ± 0.65
		Brown		2.61 ± 0.65
	Dentin	Clear		3.34 ± 0.54
		Brown		3.48 ± 0.45

Table 4. Mean and standard deviation values of color difference (ΔE) between final color of monolithic zirconia crowns and A3 shade of zirconia disk (n=8).

Crown shade	Resin core	Resin luting agent (Try-in paste)	Measurement portion	Color difference (ΔE)
A3	White	Clear	Cervical	3.75 ± 0.84
		Brown		4.27 ± 1.10
	Dentin	Clear		1.99 ± 1.06
		Brown		2.14 ± 1.14
	White	Clear	Body	3.36 ± 1.06
		Brown		3.59 ± 0.79
	Dentin	Clear		1.39 ± 0.89
		Brown		1.41 ± 0.77
	White	Clear	Incisal	2.27 ± 0.79
		Brown		2.34 ± 1.30
	Dentin	Clear		3.06 ± 1.05
		Brown		3.08 ± 0.89

Table 5. Results of three-way ANOVA analysis of color difference (ΔE) between final color of monolithic zirconia crowns and zirconia disks.

Crown shade	Source	*df*	Sum Sq	F value	*P* value
A2	Portion	2	9.7971	8.2905	0.0005*
	Abutment tooth	1	5.3723	9.0923	0.0034*
	Try-in paste	1	0.0605	0.1024	0.7498
	Portion×Abutment tooth	2	30.0647	25.4412	<.0001*
	Portion×Try-in paste	2	2.1240	1.7974	0.1719
	Abutment tooth×Try-in paste	1	0.1777	0.3007	0.5849
A3	Portion	2	5.8881	3.0316	0.0534
	Abutment tooth	1	28.2534	29.0932	<.0001*
	Try-in paste	1	0.6834	0.7038	0.4039
	Portion×Abutment tooth	2	41.0537	21.1370	<.0001*
	Portion×Try-in paste	2	0.3568	0.1837	0.8325
	Abutment tooth×Try-in paste	1	0.2563	0.2639	0.6088

df: degree of freedom, Sum Sq: sum of squares
*: Significant difference ($p<0.05$)

Table 6. Tukey's HSD test for each group.

Shade	Effect			P value
A2	Portion	Body	Cervical	0.0080*
		Body	Incisal	0.7139
		Cervical	Incisal	0.0007*
	Abutment tooth	White	Dentin	0.0034*
	Try-in paste	Clear	Brown	0.7498
A3	Portion	Body	Cervical	0.0428*
		Body	Incisal	0.5752
		Cervical	Incisal	0.3234
	Abutment tooth	White	Dentin	<.0001*
	Try-in paste	Clear	Brown	0.4039

*: Significant difference ($p<0.05$)

and W-B body portions of the A2 shade and the W-C cervical and W-B cervical portions of the A3 shade showed ΔE values of 3.7 or larger in this study. Therefore, when the abutment tooth color was white, the final color of the zirconia crown had high L* and C* values, which is considered to have caused the color difference.

In this study, the thickness of the crown differed depending on the tooth portion evaluated (Fig. 1–5). Malkondu et al. confirmed the effect of thickness on the color of monolithic zirconia. They evaluated the color changes of monolithic zirconia with two different thicknesses (0.6 and 1 mm) and three types of resin luting agents. They reported that the mean ΔE values for 0.6 mm-thick-zirconia were larger than those for 1 mm-thick-zirconia [26]. Tabatabaian et al. reported that the thickness of monolithic zirconia ceramic affected its final color, and the restoration thickness should be at least 0.9 mm to achieve an acceptable final color [13]. Furthermore, Kim et al. evaluated the effect of thickness reduction on the color and translucency of monolithic zirconia ceramics and found perceptible color differences (ΔE>3.7) when the thickness decreased from 2 to 1 mm [27]. In addition to thickness, other parameters such as translucency, the underlying resin luting agent, and color of the abutment tooth affected the final appearance of ceramic restorations [28]. In this study, the L* and C* values in the incisal portion were almost the same, regardless of the difference in the colors of the abutment tooth or the resin luting agent, because the incisal portion remained as thick as 2.0 mm. Therefore, the incisal portion did not affect the final color of monolithic zirconia crowns. In addition, for anatomical reasons, the reduced incisal portion is not thick enough to affect the final color of the crown.

It has been reported that the underlying color of the abutment tooth material can significantly affect the final color [29]. In this study, when the abutment tooth color was "dentin," the L* and C* values of the final color in the cervical and body portions were smaller than when it was "white." This result showed that the final color of the monolithic zirconia crowns was influenced by the color of the abutment tooth. In the case of an existing dark foundation, its influence should be eliminated by other factors such as the resin luting agent, zirconia coping, and/or veneering porcelain, if possible [13]. Therefore, if the abutment tooth color is dark, the abutment tooth material should be selected with a shade closer to the target color. To reproduce the final color of the crown during fabrication in the dental laboratory, it is useful to create a custom die model using wax or resin to reproduce the actual color of the abutment tooth.

Chang et al. studied the optical properties of resin-based composite cement. They concluded that the color of leucite glass-ceramic crowns and zirconia crowns could induce perceptible color changes in the cervical and body portions with specific combinations of abutment tooth material, resin luting agent, and ceramic crowns [30]. Vitch et al. stated that differences in cement thickness (0.1 or 0.2 mm) might slightly affect the final color of all-ceramic crowns [17]. In this study, the cement space was set to 50 μm; therefore, it is considered that the effect of the resin luting agent was less than that in the previous study. It has been demonstrated that the application of a resin luting agent cannot always conceal the color of the underlying abutment [31]. Application of a try-in paste in the same color as the resin luting agent helps to verify the final restoration color during crown fitting in a dental clinic site and/or fabrication in a dental lab. Furthermore, spectrophotometric measurements may be employed during fabrication and clinical trials of restorations to identify and correct possible color mismatches. The try-in pastes could be used as indicators of the final color of the crowns and as a guide to choosing an appropriate resin luting agent [32]. It has been reported that try-in pastes may not perfectly match the color shade of the resin luting agent used for the final luting of all-ceramic restorations, despite the thickness of the restoration [32, 33]. However, it was observed that the color difference between the resin luting agents and their corresponding try-in pastes is represented by a ΔE value of less than 2.0, regardless of the specimen thickness (0.5, 0.8, and 1.0 mm), which implies that there is no perceptible color difference between both materials [34]. Further, ALGhazali et al. reported that the color difference between try-in pastes and their corresponding shades of cured resin luting agents ranged between ΔE values of 1.05 and 3.34 [35]. Therefore, both materials may be considered to have a clinically acceptable color match. However, such a color agreement is not always achieved, especially when darker and more opaque luting agents are used [32]. Thus, the color match achieved by the try-in paste must be treated with caution. Try-in pastes that correspond to the same shades of resin luting agents allow dentists, patients, and dental technicians to evaluate the teeth/crowns with a focus on the color and its nuances, ensuring that esthetic expectations are achieved [34, 36].

The pre-colored monolithic zirconia ceramic disks (shade A2, A3) used in this study had lower L^* values, higher a^* values, and approximately equal b^* values as compared to Vita shades A2 and A3 according to the reference value mounted on the dental spectrophotometer used. There may be a mismatch between the selected color and the fabricated crown when the color is measured using the Vita shade guide. Della Bona et al. reported that none of the CAD/CAM ceramics (lithium disilicate-based glass-ceramic, leucite-reinforced glass-ceramic, feldspathic ceramic) were able to properly match the nominal shade to the Vita shade guide; the color differences between ceramic systems and their corresponding shade ranged from 8.16 to 12.52 for A2 and from 7.75 to 13.42 for A3 [28]. Shade guides are the most common reference used in clinical dental practice for color matching. Ideally, new dental shade guides for monolithic zirconia restorations corresponding to each material should be introduced to obtain optimum esthetics.

Color-measuring devices and systems have become increasingly popular, especially in dental research [37]. These include spectrophotometers, colorimeters, spectroradiometers, and digital image analysis techniques. These parameters are quantifiable in a reproducible and robust manner [38]. In recent years, it has become possible to automatically select tooth colors using an intraoral scanner. This technology is expected to become widespread in clinical practice in the future. Furthermore, it should be noted that the advantages of dental spectrophotometers can be appreciated even for other aspects of color reproduction, such as communicating with dental technicians [39].

The limitations of this study include the use of one type of monolithic zirconia ceramic with two shades. However, it has been reported that the translucency of zirconia differs from the brand used and is highly influenced by the thickness of the material [40]. The influence of different zirconia ceramic material products should be considered in future research.

5. Conclusion

Within the limitations of this in vitro study, the final color of the monolithic zirconia crown was found to be significantly influenced by the tooth portions evaluated (crown thickness) and the color of the abutment tooth. Clinicians should determine the shade of the abutment tooth carefully and share the information with the dental technician if sufficient crown thickness cannot be secured. From the perspective of color reproduction, it is fair to say that crown thickness is critical for expressing the optimal final color of the prosthesis.

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Conflict of interests

The authors declare that they have no conflicts of interest.

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