INFLUENCE OF ZIRCONIA/GLASS VENEER THICKNESS AND IMPLANT ABUTMENT MATERIAL ON THE FINAL SHADE OF IMPLANT RESTORATIONS

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Thesis
entitled

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Manita Woo

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ABSTRACT

This study aims to evaluate the effect of different ceramic materials and their thicknesses on the implant abutment backgrounds to the final color of restorations.

The monolithic and porcelain-veneered zirconia experimental specimens made from three translucent zirconia (Prettau Anterior, Vita YZ ST and Vita YZ HT) were prepared in the disc-shaped A3 shade with two different thicknesses (1 and 1.5 mm) (n=10). Three abutment backgrounds were prepared from the titanium, white-shaded and yellow-shaded zirconia. The zirconia specimens were placed on different backgrounds and colors (ΔE) between the experimental and the control specimens measured in the CIELab system. The results showed that the mean ΔE values between the two thicknesses were significantly different in every background for all zirconia materials. The ΔE values of the zirconia specimens on the yellow zirconia were lower than other abutments in all thicknesses. The mean ΔE within the clinically acceptable values (ΔE<3) was found in some monolithic zirconia specimens on the white-shaded and yellow-shaded abutment while the ΔE values were approximately 3 or less in all 1.5-mm-thick porcelain-veneered zirconia groups.

KEY WORDS: ZIRCONIA / GLASS / IMPLANT / TRANSLUCENCY

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LIST OF ABBREVIATIONS

CAD-CAM	: Computer-aided design/Computer aided-manufacturing
CIE	: Commission International del'Eclairage
mm	: Millimeter
nm	: Nanometer
P-PRTA	: Porcelain-veneered Prettau Anterior
PRTA	: Prettau Anterior
P-Vita HT	: Porcelain-veneered Vita YZ HT
P-Vita ST	: Porcelain-veneered Vita YZ ST
SiC	: Silicon carbide
Ti	: Titanium
Vita HT	: Vita YZ HT
Vita ST	: Vita YZ ST
ZirW	: White shaded zirconia abutment
ZirY	: Yellow shaded zirconia abutment

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CHAPTER I
INTRODUCTION

One of the major challenges in dentistry is a match between artificial teeth and natural teeth. The natural appearance of dental restorations depends not only on the size, shape, and surface form of the dentition, but also on the color and translucency that improve the appearance.[1] Translucency is the amount of light that transmits through the object. It has been reported that it is one of the critical factors for material selection to achieve the esthetic expectations.[2] The restorative material in fixed dental prostheses was developed from metal-ceramic to all-ceramic restorations, which provide superior tooth-like color and translucency than metal-ceramic restorations. Accordingly, all-ceramic materials have been developed and continuously researched for better clinical outcomes.[3]

Various types of dental ceramics have been used for all-ceramic restorations including zirconia, which has high fracture toughness to resist fracture of the restorations from the occlusal force. Thus, zirconia is currently a widespread treatment option as a restorative material in the posterior teeth.[4, 5] Because zirconia is a highly crystalline ceramic material, which the average grain size is initially less than 1 μm, the translucency of zirconia is lower than that of other dental glass-ceramics.[6] In addition, other factors such as particle size, the porosity of structure, the thickness of restorations and other components also influence the translucency of zirconia. These factors can cause the scattering of light from the material.[7, 8]

To overcome the opacity of early zirconia material, the more translucent veneering ceramic is originally applied to the zirconia framework where it can replicate the tooth-like color of the restorations.[9] However, chipping or fracture of the veneering layer is the main complication when bilayered zirconia restoration is used. Therefore, the monolithic zirconia was developed and introduced to avoid chipping or delamination of veneering glass, and it also provides better optical properties than metal-ceramic material with sufficient mechanical properties under occlusal loading.[7,

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[10, 11] Furthermore, translucency of zirconia can be improved with different methods such as modified grain size, increased cubic phase or reduced impurities in its structure to enhance tooth-colored restorations.[5, 11, 12]

The final color of zirconia restorations was affected by many factors including the thickness of zirconia and glass veneer, type of zirconia, and color of the underlying background.[13-16] In dental implants, titanium abutment is mainly used in the prosthetic part as it shows biocompatibility to oral tissue with excellent mechanical properties.[17] However, the metal color of titanium abutment may alter the color of the all-ceramic restorations that may compromise the esthetic outcome.[1] Therefore, zirconia abutment was introduced as an alternative material in the esthetic zone where it can reduce dark metal color at the gingival margin from the titanium abutment.[17, 18]

To evaluate the color shade, a spectrophotometer is used to measure the reflected light from the object and calculate in CIELab color space with high accuracy.[19-22] This system identifies the color into lightness (L*) that shows the values from 0 for black to 100 for white, red-green (a*) and blue-yellow (b*). By positive a* values defined as red and negative a* values defined as green. Also, positive b* and negative b* values define as yellow and blue, respectively.[23]

From previous studies, the effects of monolithic zirconia thickness on the masking ability to background color were observed. The results showed that the thickness of zirconia influenced the final color of the restorations.[13, 24] In addition, the color of background substrates affected the outcome of the final shade.[25, 26] Moreover, different zirconia materials and thicknesses in zirconia-based restorations also affected the final color of restorations.[9, 27-29] However, the optical effect of translucent zirconia with or without glass veneer on a different background was limited. Therefore, the aim of this present study was to investigate the optical effect of ceramic material and thickness on implant abutment background to the final color of restorations. The null hypothesis was that ceramic material, ceramic thickness and implant abutment material had no influence on the final outcome of the implant restorations.

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CHAPTER II
OBJECTIVES

The objectives of this study were to measure the optical effect of ceramic material and thickness on implant abutment background to the final color of restorations.

2.1 Statistical hypothesis

H_0: ceramic material, ceramic thickness and implant abutment material have no influence on the final color of implant restorations.

H_1: ceramic material, ceramic thickness and implant abutment material have influence on the final color of implant restorations.

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CHAPTER III
MATERIALS AND METHODS

3.1 Materials

Three different so-called translucent zirconia materials (Prettau Anterior, Vita YZ ST and Vita YZ HT) and 3 different abutment materials (Titanium, IPS e.max ZirCAD white shade and yellow shade)[30] were investigated in this study (Table 3.1).

Table 3.1 Materials used in this study

Material	Manufacturer	Composition	Shade
Prettau Anterior	Zirkonzahn GmbH, Gais, Italy	8-12% Y_2O_3, <1% Al_2O_3, 0.02% SiO_2, 0.01% Fe_2O_3	A3
Vita YZ ST	VITA Zahnfabrik, Bad Säckingen, Germany	6-8% Y_2O_3, 1-3% HfO_2, 0-1% Al_2O_3, 0-1% Pigments	A3
Vita YZ HT	VITA Zahnfabrik, Bad Säckingen, Germany	4-6% Y_2O_3, 1-3% HfO_2, 0-1% Al_2O_3, 0-1% Pigments	A3
Vita VM9 Base Dentine	VITA Zahnfabrik, Bad Säckingen, Germany	60-64% SiO_2, 13-15% Al_2O_3, 4-6% Na_2O, 7-10% K_2O, 1-2% CaO, 0-1% ZrO_2, 3-5% B_2O_3	A3
Titanium grade V	Miracle metals, Thailand	90% Ti, 6% Al, 4% V	-
IPS e.max ZirCAD	Ivoclar Vivadent AG, Schaan, Liechtenstein	4.5-6% Y_2O_3, ≤5% HfO_2, ≤1% Al_2O_3, ≤1% Other oxides for coloring	White (MO 0)
IPS e.max ZirCAD	Ivoclar Vivadent AG, Schaan, Liechtenstein	4.5-6% Y_2O_3, ≤5% HfO_2, ≤1% Al_2O_3, ≤1% Other oxides for coloring	Yellow (MO 2)

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3.2 Instruments

1. Low speed cutting machine
2. Digital micrometer
3. Polishing machine
4. Sintering furnace
5. Ultrasonic bath
6. Spectrophotometer

3.3 Methods

3.3.1 Zirconia specimens preparation

Ten specimens in 12-mm diameter with 2 different thicknesses (1 mm and 1.5 mm) were tested in each zirconia material (Table 3.2). The sample size was estimated from the results of the previous study[6] with a significant level (α) at 0.05 and power of the test at 80%.

The ceramic was prepared using a low-speed diamond saw cutting machine (IsoMet; Buheler, Lake Bluff, IL, USA) into 3 different thicknesses (0.5, 1 and 1.5 mm). For the monolithic zirconia groups, a total of 60 specimens of 1 mm and 1.5 mm thick were made (n=10) (Table 3.2). The Prettau Anterior specimens were immersed in A3 shade coloring liquid for 1 second (Colour liquid Prettau Anterior Aquarell A3 shade; Zirkonzahn GmbH, Gais, Italy) (Figure 3.1) and subsequently removed to be dried for 20 min under drying lamp (Zirkonlampe 250; Zirkonzahn GmbH, Gais, Italy) before sintering in furnace at a temperature of 1450°C (Zirkonofen 600; Zirkonzahn GmbH, Gais, Italy) following the manufacturer's instruction. The Vita YZ ST and Vita YZ HT zirconia specimens were fired according to the recommended temperatures (Vita YZ ST at 1530°C and Vita YZ HT at 1450°C) in a sintering furnace (inFire HTC speed; Sirona, Bensheim, Germany). After the sintering process, all specimens were polished with 600, 800, 1000, 1200 grit silicon carbide paper under water coolant (Phoenix Beta; Buehler, Lake Bluff, IL, USA). The final thickness of all specimens was verified by a digital micrometer (Digimatic

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Micrometer; Mitutoyo, Japan) at 5 different points on the surface of each sample (Figure 3.2).

Table 3.2 Zirconia specimens in this study

Material	Zirconia thickness (mm)	Veneer thickness (mm)	Total thickness (mm)	Symbol
Monolithic zirconia groups				
Prettau Anterior	1	-	1	PRTA
	1.5	-	1.5	
Vita YZ ST	1	-	1	Vita ST
	1.5	-	1.5	
Vita YZ HT	1	-	1	Vita HT
	1.5	-	1.5	
Porcelain-veneered zirconia groups				
Prettau Anterior	0.5	0.5	1	P-PRTA
	0.5	1	1.5	
Vita YZ ST	0.5	0.5	1	P-Vita ST
	0.5	1	1.5	
Vita YZ HT	0.5	0.5	1	P-Vita HT
	0.5	1	1.5	

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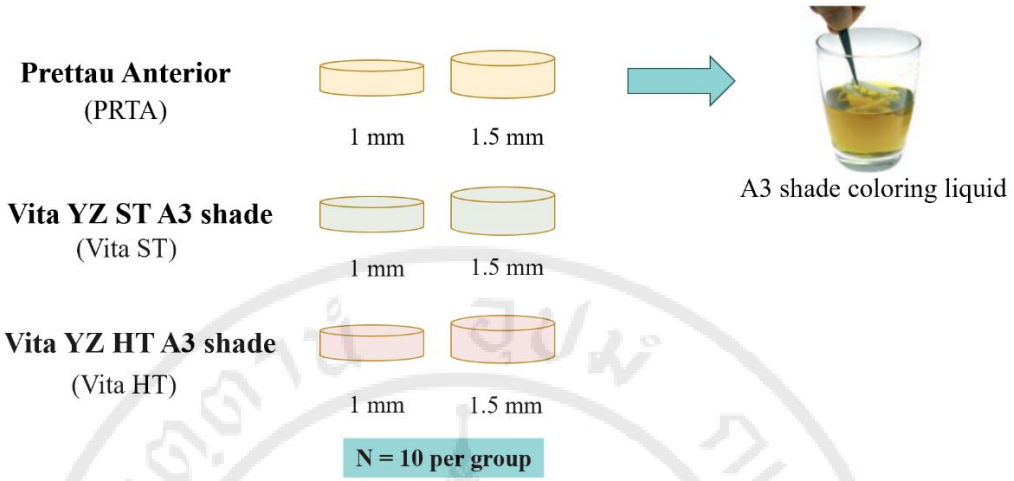

Figure 3.1 Monolithic zirconia specimens preparation

For porcelain-veneered zirconia groups, sixty specimens of 0.5-mm-thick zirconia made from 3 different A3 shade zirconia materials were prepared. Each material was divided into two groups for layering with compatible A3 shade veneering ceramic (Vita VM9 Base Dentine; VITA Zahnfabrik, Bad Säckingen, Germany) to derive the final thickness of 1 mm and 1.5 mm (n=10) (Table 3.2) as shown in figure 3.2. The specimens were layered using a plastic mold on which size was considered the shrinkage of the ceramic after firing process (Figure 3.3). All veneered ceramics were fired in a furnace (VITA V60 i-Line; VITA Zahnfabrik, Bad Säckingen, Germany) according to the manufacturer's guideline and subsequently ground with 600-1200 grit SiC paper on the polishing machine (Phoenix Beta; Buehler, Lake Bluff, IL, USA). The final thickness of each sample was verified with a digital micrometer (Digimatic Micrometer; Mitutoyo, Japan).

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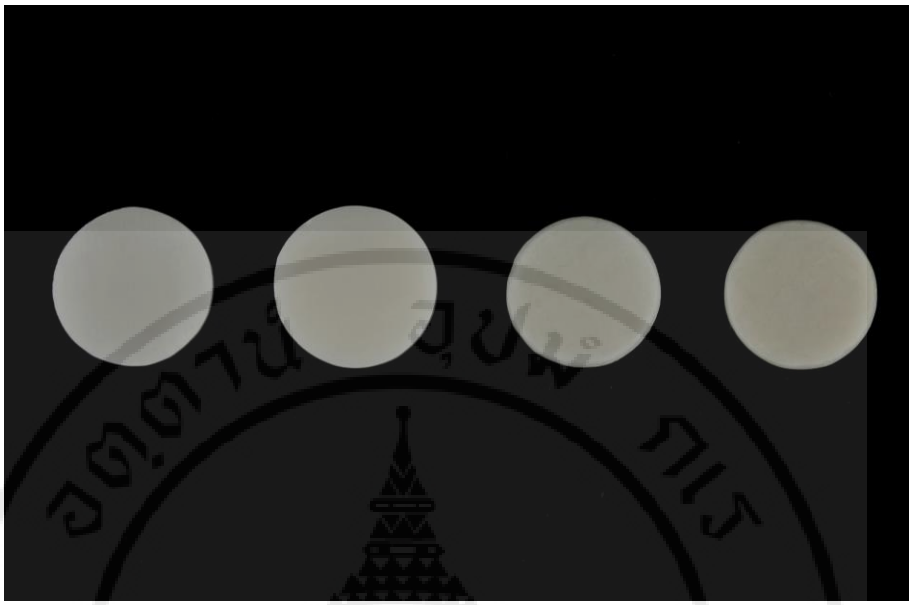

Figure 3.2 Zirconia specimens; monolithic zirconia thickness of 1 and 1.5 mm, porcelain-veneered zirconia thickness of 1 and 1.5 mm (from left to right)

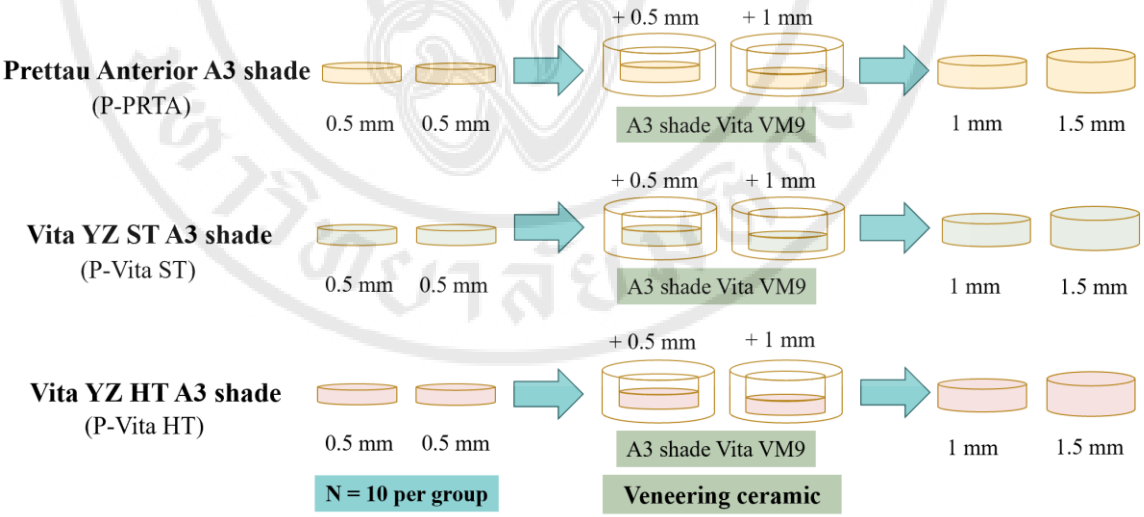

Figure 3.3 Porcelain-veneered zirconia specimens preparation

3.3.2 Control specimens preparation

For the control specimens, three types of translucent zirconia with A3 shade (Prettau Anterior, Vita YZ ST and Vita YZ HT) were made in 4-mm thickness as a control sample of each monolithic zirconia type. For the control samples of veneered zirconia groups, veneering ceramic (Vita VM9 Base Dentine A3 shade) was made in 4-mm thickness using a plastic mold (Figure 3.4). All control specimens were

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sintered and polished with the silicon carbide paper from 600 to 1200 grit under water coolant, then the final thickness was verified using a digital micrometer (Digimatic Micrometer; Mitutoyo, Japan).

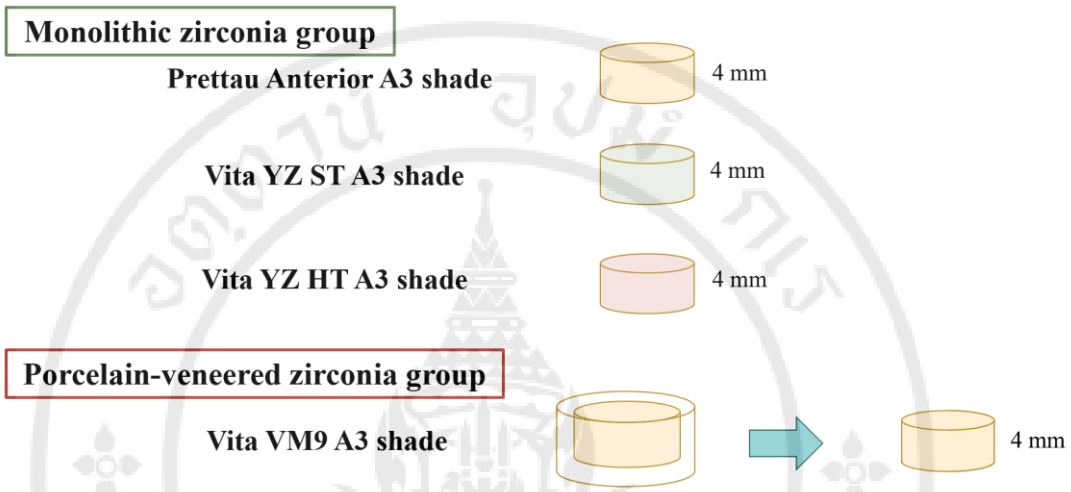

Figure 3.4 Control specimens preparation

3.3.3 Abutment specimens preparation

Three different types of simulated implant abutments were prepared as 2-mm-thick plates from titanium grade V (Ti), IPS e.max ZirCAD MO 0 white shade (ZirW) and IPS e.max ZirCAD MO 2 yellow shade (ZirY) (Figure 3.5). To fabricate the titanium background, titanium blank was designed and sectioned with lathe machine (SJ-430×1000; ECOCA, Taiwan) to the specified thickness. For zirconia backgrounds, zirconium dioxide blocks were cut with a low-speed cutting machine (IsoMet; Buheler, Lake Bluff, IL, USA). Subsequently, the zirconia backgrounds were fired in sintering furnace (inFire HTC speed, Sirona, Bensheim, Germany) and adjusted to the desired thickness. A digital micrometer was used to verify the thickness of specimens at 5 different points on the surface. All backgrounds and zirconia specimens were cleaned in an ultrasonic bath (Quantrex 210H; L&R Manufacturing Co., Kearny, USA) using distilled water for 10 minutes and dried before color measurement.

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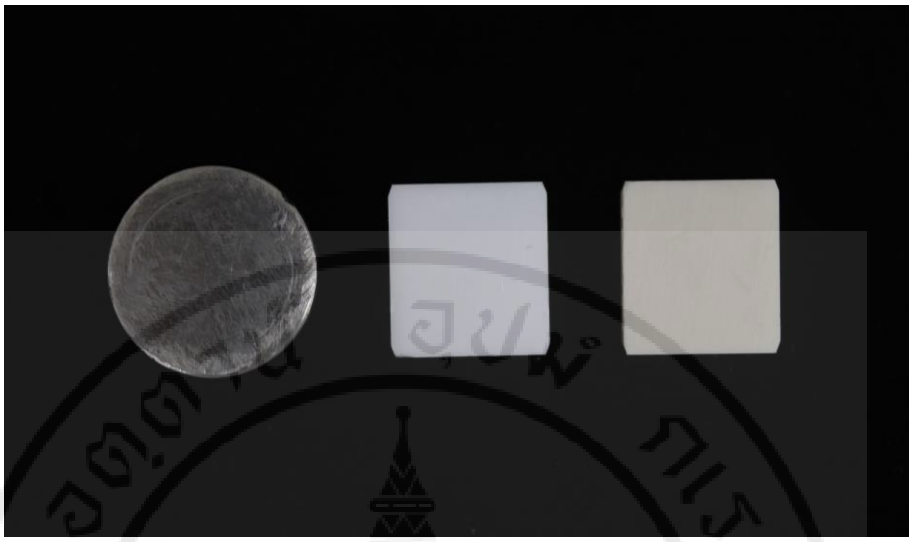

Figure 3.5 Abutment specimens; Ti, ZirW, ZirY (from left to right)

3.3.4 Color measurement

Color parameters were conducted by a spectrophotometer (Ultrascan Pro; Hunterlab, Reston, USA) with a wavelength range of 360 to 780 nm and standard illuminant D65/10° (Figure 3.6). The spectrophotometer was calibrated before the color analysis according to the instruction of the device. Each tested specimen was placed over the different backgrounds, and clear glycerin was dropped between two materials to improve optical contact. The tip of the spectrophotometer was placed at the center of the sample. Color measurement of all specimens was repeated three times and recorded in the CIELab system, which demonstrates in L*, a* and b* data in three-dimensional color space. The color difference between control and tested specimens was calculated in ΔE using the equation $\Delta E=[(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}$.

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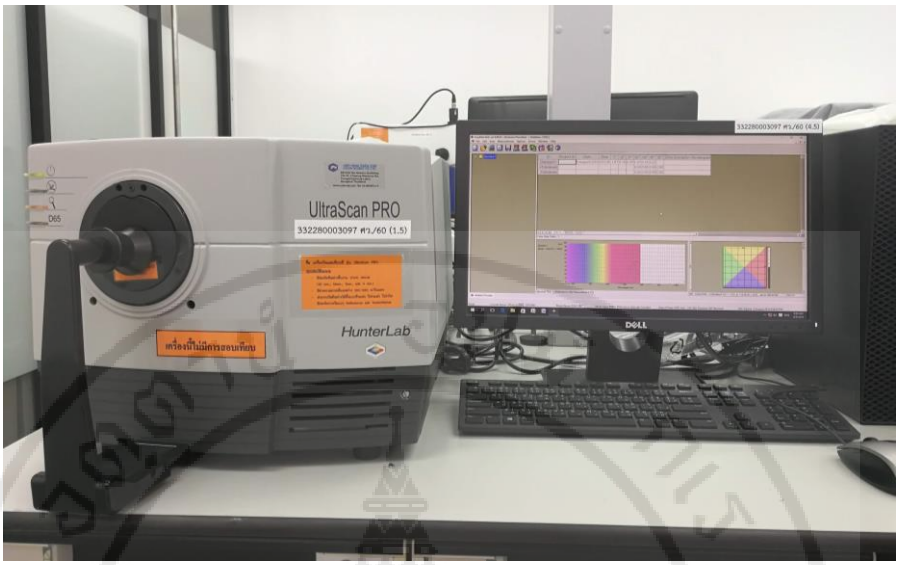

Figure 3.6 Spectrophotometer spectrophotometer (Ultrascan Pro; Hunterlab)

3.3 Statistical analysis

The data analysis was performed using statistical software (IBM SPSS Statistics version 22.0; IBM Corp, Armonk, NY, USA). The findings of the Kolmogorov-Smirnov test and Levene's test showed that the data from this study were normally distributed ($p>0.05$) and variances were homogeneous ($p>0.05$). The three-way ANOVA ($\alpha=0.05$) was performed to evaluate the ΔE among the groups considering the factors of ceramic material, ceramic thickness, and abutment type. For the multiple comparisons, the Scheffé test was used to analyze the data ($\alpha=0.05$).

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CHAPTER IV
RESULTS

The three-way ANOVA results for monolithic zirconia groups (Table 4.1) indicated that zirconia material, ceramic thickness, and abutment background, significantly affected the ΔE ($p<0.001$). The means and standard deviations of ΔE values with the Scheffé multiple comparisons are shown in Table 4.2

Table 4.1 Three-way ANOVA results of ΔE values for monolithic zirconia groups

Source	Sum of Squares	df	Mean Square	F	Sig.
Material	15.841	2	7.920	51.891	.000
Thickness	156.844	1	156.844	1027.587	.000
Background	313.012	2	156.506	1025.377	.000
Material x Thickness	2.589	2	1.294	8.480	.000
Material x Background	22.785	4	5.696	37.319	.000
Thickness x Background	25.564	2	12.782	83.745	.000
Material x Thickness x Background	7.649	4	1.912	12.528	.000
Error	24.727	162	.153		
Total	**3148.159**	**180**			

A monolithic zirconia specimen on titanium abutment showed more grayish shade, and a specimen on white-shaded background presented brighter color than control specimen. However, the color of zirconia restoration over yellow-shaded abutment was more similar to the control than the others (Figure 4.1-4.2).

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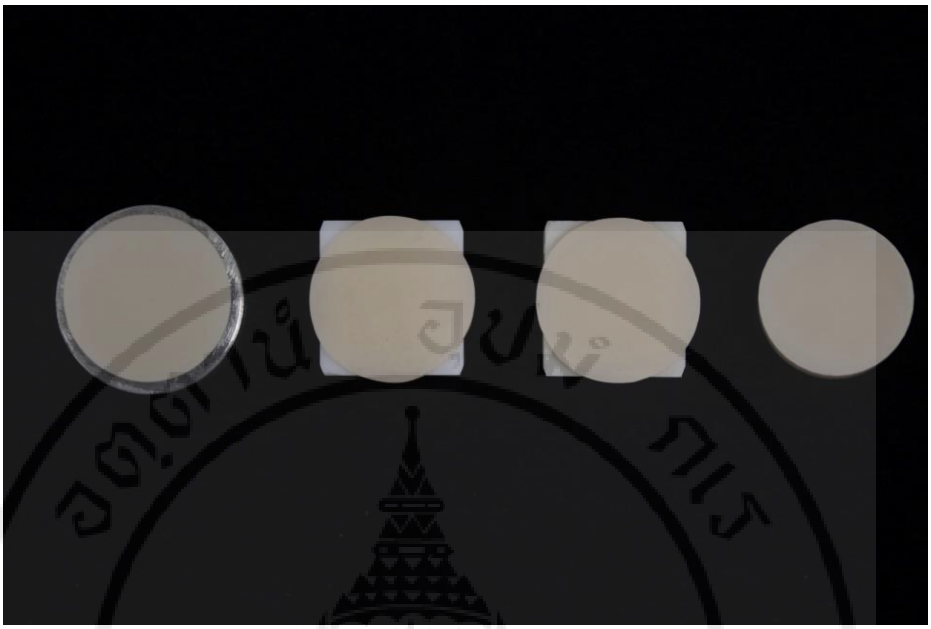

Figure 4.1 Monolithic zirconia specimen thickness of 1 mm on Ti, ZirW, ZirY abutment and control specimen (from left to right)

Figure 4.2 Monolithic zirconia specimen thickness of 1.5 mm on Ti, ZirW, ZirY abutment and control specimen (from left to right)

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The mean ΔE within clinical acceptable value (ΔE<3) were found in all monolithic zirconia specimens on ZirY abutment and in 1.5-mm-thick of PRTA and

Vita ST on ZirW abutment (Table 4.2). However, the ΔE value of 1-mm-thick PRTA specimens on ZirY was greater than 3, where it was considered clinically noticeable.

The multiple comparisons indicated that ΔE value of 1-mm-thick PRTA on Ti background was significantly higher than those of the other specimens. When ceramic thickness was compared, the ΔE values between 1- and 1.5-mm-thick specimens were significantly different in each abutment background for all zirconia materials. Significant differences were also found between Ti and ZirY backgrounds in each zirconia thickness of three materials. The same outcomes were similar between ZirW and ZirY abutments except for 1.5-mm-thick PRTA ($p>0.05$). There were significant differences between Ti and ZirW abutments with 1.5-mm-thick specimens in all monolithic zirconia materials ($p<0.05$) except for Vita HT.

Table 4.2 Mean ± standard deviation of ΔE values and multiple comparisons for monolithic zirconia groups. The same superscripts indicate no significant difference between groups ($p>0.05$)

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
PRTA	1	6.94 ± 0.59^{i}	5.71 ± 0.73^{h}	3.27 ± 0.49^{de}
	1.5	5.72 ± 0.44^{h}	1.84 ± 0.28^{ab}	1.74 ± 0.20^{ab}
Vita ST	1	5.57 ± 0.27^{gh}	5.17 ± 0.32^{gh}	2.55 ± 0.22^{bcd}
	1.5	4.66 ± 0.23^{fg}	2.30 ± 0.33^{bc}	1.22 ± 0.66^{a}
Vita HT	1	5.44 ± 0.24^{gh}	5.17 ± 0.24^{gh}	2.63 ± 0.31^{bcd}
	1.5	3.74 ± 0.24^{ef}	3.14 ± 0.28^{cde}	1.31 ± 0.37^{ac}

For porcelain-veneered zirconia groups, the results of three-way ANOVA revealed that ceramic thickness and abutment material significantly influenced the ΔE values ($p<0.05$). However, the material had no influence on the ΔE values ($p=0.876$) (Table 4.3). The color of porcelain-veneered zirconia specimens was also affected by the color of the underlying abutments. A zirconia specimen on yellow-shaded abutment displayed the most similarity of color to the control (Figure 4.3-4.4).

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Table 4.3 Three-way ANOVA results of ΔE values for porcelain-veneered zirconia groups

Source	Sum of Squares	df	Mean Square	F	Sig.
Material	.032	2	.016	.132	.876
Thickness	345.650	1	345.650	2884.393	.000
Background	90.343	2	45.171	376.948	.000
Material x Thickness	1.603	2	.801	6.688	.002
Material x Background	2.182	4	.546	4.553	.002
Thickness x Background	19.324	2	9.662	80.629	.000
Material x Thickness x Background	21.936	4	5.484	45.763	.000
Error	19.413	162	.120		
Total	**2496.974**	**180**			

The mean ΔE values of the ceramics with 1.5-mm thickness were clinically acceptable where the ΔE values are approximately 3 or less. The results of multiple comparisons for veneered zirconia groups showed that 1-mm-thick P-PRTA specimens on Ti background, 1-mm-thick P-Vita ST and P-Vita HT on ZirW background had greater ΔE values than those of the other specimens. The ΔE values between 1- and 1.5-mm-thick ceramic specimens were significantly different in every background for all zirconia materials ($p<0.05$). When the abutment backgrounds were considered, the ΔE values of ZirY groups were lower than those of Ti and ZirW groups in all thicknesses (Table 4.4).

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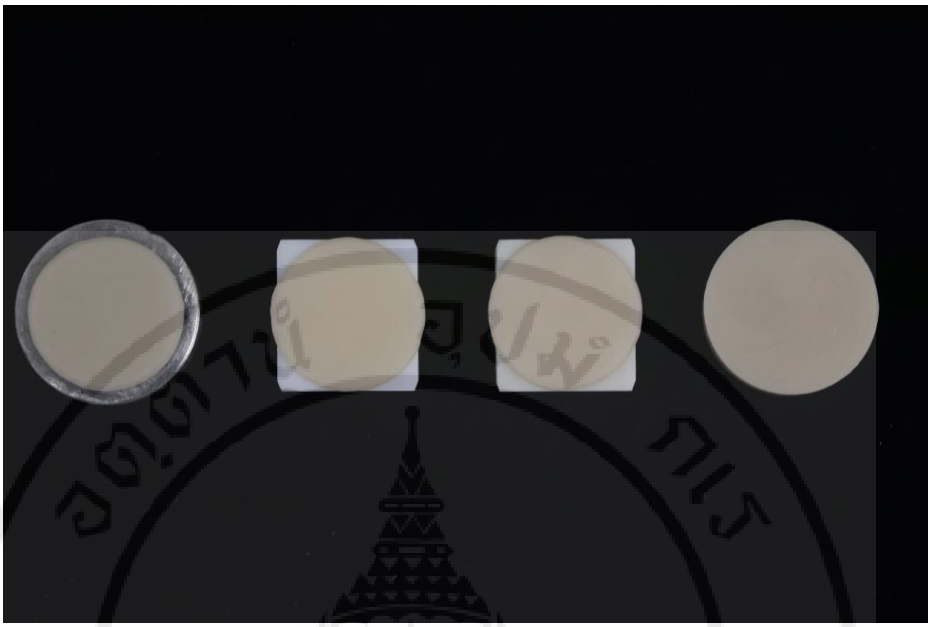

Figure 4.3 Porcelain-veneered zirconia specimen thickness of 1 mm on Ti, ZirW, ZirY abutment and control specimen (from left to right)

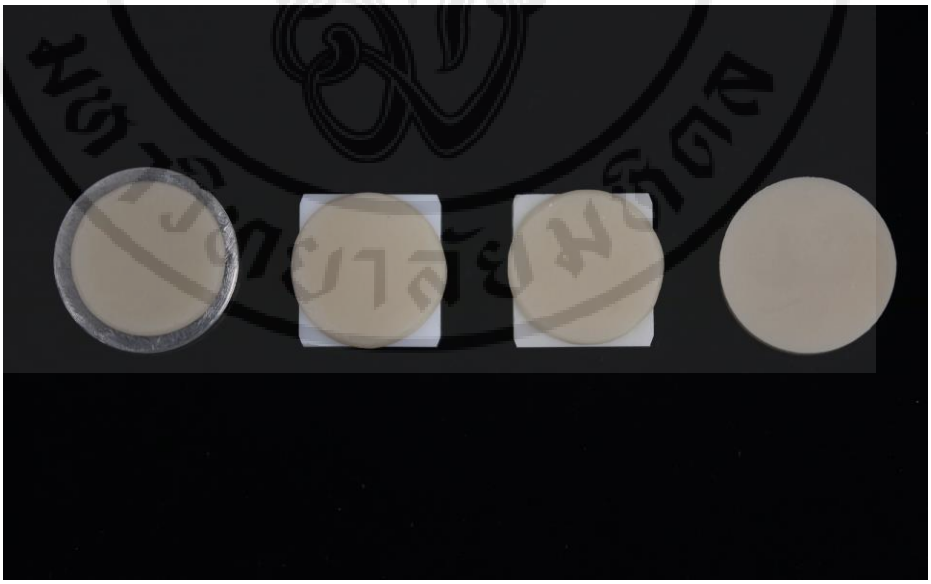

Figure 4.4 Porcelain-veneered zirconia specimen thickness of 1.5 mm on Ti, ZirW, ZirY abutment and control specimen (from left to right)

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Table 4.4 Mean ± standard deviation of ΔE values and multiple comparisons for porcelain-veneered zirconia groups. The same superscripts indicate no significant difference between groups ($p>0.05$)

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
P-PRTA	1	5.90 ± 0.49^{ij}	5.09 ± 0.46^{ghi}	3.16 ± 0.37^{e}
	1.5	2.31 ± 0.32^{cd}	2.28 ± 0.25^{cd}	1.32 ± 0.67^{ab}
P-Vita ST	1	4.88 ± 0.64^{gh}	5.94 ± 0.27^{j}	3.72 ± 0.45^{ef}
	1.5	3.02 ± 0.14^{e}	1.29 ± 0.28^{ab}	1.01 ± 0.23^{a}
P-Vita HT	1	4.51 ± 0.24^{fg}	5.59 ± 0.31^{hij}	3.67 ± 0.35^{e}
	1.5	2.96 ± 0.30^{de}	1.97 ± 0.20^{bc}	1.18 ± 0.28^{ab}

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CHAPTER V
DISCUSSION

Based on the results of this in vitro study, the null hypothesis was rejected because zirconia material, ceramic thickness and types of abutment background affected the color difference.

The optical effect of all-ceramic restorations has been evaluated in previous studies.[6, 13, 24-26, 28] Nevertheless, there was no consensus on the optical effect of translucent zirconia on different implant abutments. In this present study, two different thicknesses of three zirconia materials for monolithic and porcelain-veneered zirconia restorations were investigated. The findings showed that the thickness of zirconia significantly influenced the overall color of restorations. In this study, it was demonstrated that the 1-mm-thick ceramics in both monolithic and bilayered zirconia were inadequate to mask the color of the underlying abutments. However, when the thickness was increased to 1.5 mm, such the masking effect was also practically increased that the influence of the underlying materials diminished, since the dental ceramic allows some degree of light passing through the material and the translucency is related to its thickness.[5, 24]

Implant abutment materials influenced the final color differently as they had different color properties.[25] In this study, $\Delta E=3$ was assumed as an acceptability threshold of the human eyes to describe the color difference.[31] The results showed that all zirconia restorations with a thickness of 1.5 mm over yellow-shaded zirconia background presented superior color-matching with acceptable esthetic color ($\Delta E<3$). Nonetheless, titanium background provided greater color difference. These could be reasoned that yellow-shaded abutment had similar color to the control specimens. The yellow-shaded background showed less color difference than that of titanium and white zirconia backgrounds regardless of monolithic or bilayered zirconia.

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As zirconia is a semitranslucent material, which permits more light transmission and has less light absorption than metal abutment, when all-ceramic

material was restored on zirconia abutment, it showed more preferable outcome than metal abutment, which caused darker color to the final restorations. Likewise, previous in vivo studies suggested that zirconia abutment should be employed in the area of high esthetic demand rather than titanium abutment.[32, 33]

The previous study reported that reduction of monolithic zirconia from 2 mm to 1 mm resulted in perceptible color difference ($\Delta E>3.7$).[24] This was comparable to the finding of this study that the thickness of zirconia altered the final color of restorations. However, it was reported that minimum thickness of monolithic zirconia should not be less than 0.9 mm to reach acceptable color when restorations were placed on A4 shade background.[13] Furthermore, it was shown that monolithic zirconia of 1.8 mm was inadequate to cover metal and discolored tooth shade substrates while porcelain-veneered zirconia restoration of 0.8 mm zirconia framework with 1 mm veneering ceramic provided adequate thickness for masking only in discolored tooth shade backgrounds.[26] In addition, the results from another study presented that zirconia coping thickness and veneering ceramic thickness should be more than 0.6 mm and 1.2 mm, respectively to cover the titanium background, base metal alloy and A3 shade zirconia abutment.[6] The conflict of minimum ceramic thickness from this present study could be attributed to different zirconia materials and methods designed in this test.

Because zirconia is mainly composed of crystalline contents in its structure, light scattering is occurred through the materials and resulted in high opacity. To improve the optical properties of zirconia, translucent zirconia has been developed to enhance esthetic appearance. Thus, zirconia brands with different levels of translucency may cover substrate color differently. In this study, the Prettau Anterior zirconia was reported by the manufacturer that it composed of 8-12% wt yttria with more than 50% cubic phase zirconia, which is higher in content than that of Vita YZ ST and Vita YZ HT zirconia. Therefore, the increased volume of isotropic structures resulted in reduced light scattering at the grain boundaries.[11, 12, 34] The results of this study showed that 1-mm-thick Prettau Anterior specimens on titanium abutment had higher ΔE than those of the other specimens. These could be caused by higher translucency of Prettau Anterior zirconia that allowed more light transmission.

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Therefore, the background effect was more distinct than the other zirconia materials in this study.

Although highly translucent zirconia was developed for better clinical outcome, the shade and translucency of the restoration are frequently dissimilar to the adjacent teeth because of the highly crystalline nature of zirconia. Accordingly, glass veneer is frequently applied to the anatomical design zirconia framework to imitate natural-like tooth color.[6, 35] Generally, the zirconia framework with veneering porcelain could be made only on the labial or buccal surface to achieve adequate esthetic result while stronger zirconia was designed on the lingual or occlusal surface to resist fracture of restorations from mastication.[36] Nevertheless, research should be taken on the bonding quality between zirconia and glass veneer to avoid the chipping and delamination problem between two different ceramic materials.[37]

This study found that the appropriate thickness for porcelain-veneered zirconia groups to achieve color matching was 1.5 mm, which was in agreement with the results by Oh and Kim[28] that reported most of the 1.5-mm-thick zirconia-based restorations could cover base metal alloy, tooth-colored shade and gold alloy abutment with a clinically acceptable color difference ($\Delta E<2.6$). Even though 1-mm-thick ceramic could be enough to cover metal abutment, it may be because of the different microstructure of zirconia used in the study. In addition, the previous study used a colorimeter to measure the color of specimens that may cause edge loss effect where some reflected light cannot completely turn back through the small window of the device. This effect may reduce the accuracy of color measurement.[38] Also, a portable spectrophotometer may not be precise in color determination as position of equipment could affect the color assessment.[39]

In bilayered zirconia, glass veneering ceramic which has high translucency was applied on a zirconia framework.[40] However, the bilayered ceramic with 1.5-mm thickness had a higher ability to cover background than the monolithic zirconia with equal thickness although the veneer layer is intrinsically more translucent than the zirconia. These could be explained by the different refractive index between glass veneering ceramic and zirconia core, and also the interface effect, which increased light scattering and reflection at the interface between two layers and therefore these improved masking ability.[41, 42] This would be beneficial when the bilayered zirconia is

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employed over the underlying titanium or discolored substrates according to this ability and the greater translucency from the glass property.

The control specimens used in this study were the 4-mm-thick ceramic plates of monolithic zirconia or glass veneer for the reason that these ceramic plates represented the expected shade of the final restorations. However, due to the opaque white color of zirconia, the color of zirconia may not match with the commercial shade guides that usually based on the Vita shade system. Therefore, a custom shade guide for zirconia may be required for color matching in clinical situations.

This in vitro study evaluated the effect of ceramic thickness on implant abutment using only one shade color of restorations without using luting cement. The result may differ if the lighter or darker shade of restorations and luting cement were used. There should be further study to include the other factors as they could influence the overall color of restorations.

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CHAPTER VI
CONCLUSION

1. The different translucent zirconia materials on implant abutments affected the final color of restorations.

2. The yellow-shaded zirconia implant abutment provided the most appropriate color for monolithic zirconia and porcelain-veneered zirconia restorations.

3. The minimum thickness of monolithic translucent zirconia and zirconia-based restorations on yellow abutment should be at least 1.5 mm to achieve satisfactory outcome.

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APPENDIX

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Monolithic zirconia groups

Mean ± standard deviation of L values for monolithic zirconia

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
PRTA	1	68.03±0.72	77.81±0.73	74.94±0.69
	1.5	68.73±1.02	73.44±0.56	71.96±0.71
Vita ST	1	68.88±0.62	76.03±0.58	73.79±0.81
	1.5	69.35±0.56	72.94±0.64	71.66±0.73
Vita HT	1	72.46±0.36	79.88±0.35	77.59±0.39
	1.5	73.48±0.37	77.70±0.23	76.30±0.34

Mean ± standard deviation of a values for monolithic zirconia

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
PRTA	1	-1.85±0.19	-1.92±0.32	-1.25±0.25
	1.5	-2.19±0.18	-1.88±0.21	-1.58±0.16
Vita ST	1	-0.68±0.07	1.11±0.06	1.19±0.05
	1.5	-0.38±0.15	1.61±0.14	1.39±0.14
Vita HT	1	-0.92±0.07	0.24±0.08	0.50±0.07
	1.5	-0.73±0.09	0.83±0.06	0.70±0.07

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Mean ± standard deviation of b values for monolithic zirconia

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
PRTA	1	3.71±0.89	9.57±1.06	9.41±0.79
	1.5	4.70±0.57	8.51±0.80	8.35±0.59
Vita ST	1	8.30±0.39	15.82±0.49	14.22±0.37
	1.5	9.04±0.45	14.36±0.61	13.19±0.67
Vita HT	1	6.97±0.35	14.09±0.29	12.85±0.31
	1.5	8.40±0.43	13.45±0.32	12.15±0.41

Mean ± standard deviation of ΔL values for monolithic zirconia

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
PRTA	1	-4.27±0.72	5.50±0.73	2.63±0.69
	1.5	-3.58±1.02	1.13±0.56	-0.34±0.71
Vita ST	1	-3.26±0.62	3.89±0.58	1.66±0.81
	1.5	-2.78±0.56	0.81±0.64	-0.48±0.73
Vita HT	1	-3.26±0.36	4.15±0.35	1.86±0.39
	1.5	-2.25±0.37	1.97±0.23	0.57±0.34

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Mean ± standard deviation of Δa values for monolithic zirconia

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
PRTA	1	1.06±0.19	0.98±0.32	1.66±0.25
	1.5	0.72±0.18	1.02±0.21	1.33±0.16
Vita ST	1	-1.58±0.07	0.20±0.06	0.28±0.05
	1.5	-1.28±0.15	0.71±0.14	0.49±0.14
Vita HT	1	-1.50±0.07	-0.34±0.08	-0.09±0.07
	1.5	-1.31±0.09	0.25±0.06	0.12±0.07

Mean ± standard deviation of Δb values for monolithic zirconia

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
PRTA	1	-5.28±0.89	0.58±1.06	0.42±0.79
	1.5	-4.29±0.57	-0.48±0.80	-0.64±0.59
Vita ST	1	-4.18±0.39	3.34±0.49	1.73±0.37
	1.5	-3.45±0.45	1.87±0.61	0.71±0.67
Vita HT	1	-4.06±0.35	3.05±0.29	1.82±0.31
	1.5	-2.63±0.43	2.42±0.32	1.11±0.41

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Porcelain-veneered zirconia groups

Mean ± standard deviation of L values for porcelain-veneered zirconia

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
P-PRTA	1	66.79±0.44	73.86±0.46	72.00±0.46
	1.5	69.03±0.47	71.36±0.26	70.57±0.42
P-Vita ST	1	67.78±0.56	74.68±0.28	72.74±0.39
	1.5	67.48±0.19	69.78±0.34	68.91±0.20
P-Vita HT	1	67.61±0.26	74.31±0.39	72.57±0.41
	1.5	67.57±0.26	70.16±0.42	69.35±0.41

Mean ± standard deviation of a values for porcelain-veneered zirconia

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
P-PRTA	1	0.21±0.14	1.30±0.30	1.44±0.23
	1.5	1.70±0.12	2.81±0.22	2.73±0.20
P-Vita ST	1	0.62±0.21	2.21±0.29	2.28±0.26
	1.5	1.87±0.10	3.20±0.06	2.97±0.17
P-Vita HT	1	0.78±0.11	2.13±0.21	2.25±0.15
	1.5	1.83±0.18	3.11±0.19	2.90±0.17

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Mean ± standard deviation of b values for porcelain-veneered zirconia

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
P-PRTA	1	10.58±0.40	16.94±0.38	15.90±0.28
	1.5	13.16±0.23	16.21±0.21	15.49±0.23
P-Vita ST	1	11.10±0.63	17.75±0.59	16.57±0.63
	1.5	12.89±0.27	15.96±0.28	15.07±0.43
P-Vita HT	1	11.57±0.26	17.68±0.30	16.79±0.25
	1.5	13.29±0.46	16.57±0.30	15.70±0.28

Mean ± standard deviation of ΔL values for porcelain-veneered zirconia

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
P-PRTA	1	-2.93±0.44	4.14±0.46	2.28±0.46
	1.5	-0.69±0.47	1.641±0.26	0.85±0.42
P-Vita ST	1	-1.94±0.56	4.96±0.28	3.02±0.39
	1.5	-2.24±0.19	0.06±0.34	-0.81±0.20
P-Vita HT	1	-2.11±0.26	4.59±0.39	2.85±0.41
	1.5	-2.15±0.26	0.44±0.42	-0.37±0.41

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Mean ± standard deviation of Δa values for porcelain-veneered zirconia

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
P-PRTA	1	-3.00±0.14	-1.90±0.30	-1.77±0.23
	1.5	-1.50±0.12	-0.40±0.23	-0.48±0.20
P-Vita ST	1	-2.59±0.21	-0.99±0.29	-0.93±0.26
	1.5	-1.33±0.10	0.00±0.06	0.23±0.17
P-Vita HT	1	-2.43±0.11	-1.08±0.21	-0.96±0.15
	1.5	-1.38±0.18	-0.10±0.19	-0.31±0.17

Mean ± standard deviation of Δb values for porcelain-veneered zirconia

Material	Thickness (mm)	Background		
		Ti	ZirW	ZirY
P-PRTA	1	-4.13±0.40	2.23±0.38	1.19±0.29
	1.5	-1.56±0.23	1.49±0.21	0.78±0.23
P-Vita ST	1	-3.62±0.63	3.04±0.59	1.85±0.63
	1.5	-1.63±0.26	1.24±0.28	0.36±0.43
P-Vita HT	1	-3.14±0.26	2.97±0.30	2.08±0.25
	1.5	-1.43±0.46	1.85±0.30	0.99±0.28

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