European Journal of Prosthodontics and Restorative Dentistry (2023) **31**, 40-49

Effects of Ceramic Thickness and Titanium Anodization on Esthetic Outcomes of Lithium Disilicate Ceramic Over Titanium Alloys

Keywords

Titanium
Zirconia
Lithium Disilicate
Color Differences
Anodization
Esthetic

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Received: 21.01.2022
Accepted: 20.04.2022

doi: 10.1922/EJPRD_2397Weeranoppanant10

ABSTRACT

Objective: In order to investigate the esthetic outcomes via color differences of various lithium disilicate ceramic thicknesses on various voltages of anodized titanium. Materials and methods: 28 lithium disilicate ceramic specimens (medium translucency) were arranged into four groups based on the thickness of the ceramic: 1.0, 1.5, 2.0, and 2.5 mm (n=7). Each group was tested with seven different materials (n=7): composite resin (A2-dentin shade, control), zirconia, titanium, 40 V (blue), 50 V (light yellow), 60 V (yellow) and 70 V (pink)-anodized titanium. All the specimens were measured with a spectrophotometer, and then compared with the composite resin (control) to establish the color differences. To be considered as clinically acceptable, the color differences must be lower than 2.7. The data obtained was statistically analyzed through ANOVA and a post hoc test (p=0.05). Results: Both the thickness of the lithium disilicate ceramics and the type of material had a significant effect on the color differences observed (p<0.05). When ceramics thickness more than 2.0 mm were used for zirconia or 2.5-mm ceramic thickness for yellow-shade (50 V and 60 V) of anodized titanium, the color differences obtained were below the clinical acceptability values. Conclusions: yellow-shade of anodized titanium tends to achieve esthetics in combination with adequate ceramic thickness.

INTRODUCTION

The demand for tooth-colored restorations has increased greatly over the past decade; the major motivation being esthetics. Dental ceramics emerged as a common material for this application,[1-3] but tuning the optical properties of the material remains challenging. To achieve a desired esthetic outcome, the optical properties of the material must match those of the natural tooth, both in terms of color and translucency while also maintaining satisfactory mechanical properties.[4,5] Among different ceramics, lithium disilicate proved to be a promising option with its excellent mechanical and optical properties.[6,7] Although lithium disilicate has excellent optical properties, it can encounter problems when applied with darker foundation. Moreover, several studies demonstrated that all factors; ceramic thickness, translucency and foundation color, were considerably effected final color of lithium disilicate. Whereas, cement color and thickness only caused minimal effects.[8-10] Although several studies confirmed that low translucency or opaque material can mask the foundation,[8,11,12] the highest translucency are preferable to achieve aesthetic outcome. However, the previous study showed that high translucency of lithium disilicate cannot provide adequate masking for darker foundation.[8] Therefore, medium translucency seem to be a choice of interest on this study.

Missing teeth can have a detrimental effect on patients' self-confidence, especially if it is highly visible due to occurring in the esthetic zone.[13] Dental implants are an effective treatment to address this problem at general positions with a high success rate.[14-16] However, creating effective dental implants in the esthetic zone remains challenging because of the treatment must satisfy both esthetic and functional requirements. In some cases, compromising between these two aspects lowers the success rate of the treatment. Among different potential materials, titanium emerged as a dominant material for dental implants because of its biocompatibility, corrosion resistance and fatigue resistance. However, dental implants made out of titanium consists of two components, a fixture and an abutment, which appear grayish.[17,18] The grayish appearance of titanium often shines through the dental ceramic restoration and peri-implant soft tissue (especially in thin biotype).[19-21] Previous research demonstrated that titanium creates the highest color difference with lithium disilicate ceramic relative to other abutment materials (gold-palladium and zirconia).[19,20] Although, using an aesthetic abutment (zirconia abutment and two-piece or hybrid abutment) may solve the issue with titanium abutments, mechanical failure from these abutments remains a concern due to the property differences between zirconia and the titanium core or fixture.[22] Therefore, the modification of titanium abutments seem to be a good choice to improve the aesthetic outcome.

Several techniques have been proposed to improve titanium abutments such as chemical oxidation, thermal oxidation, titanium nitride and anodization. Unfortunately, many of these techniques have some disadvantages. Chemical-oxidized abutments show low durability, while thermal oxidation is difficult to control and reproduce.[23,24] Titanium nitride can cause allergic reactions for some patients.[25] In contrast, abutments modified via anodization are found to be durable and easy to control with a high degree of repeatability.[26,27] Furthermore, the anodization process generates an oxide layer on the outer surface of the titanium, which can enhance corrosion resistance and biocompatibility. Anodized titanium may present different colors depending on factors such as voltage, electrolyte concentration and temperature used. From these, voltage is the only factor that can be simply controlled to increase the formation of oxide layers.[28] The increasing of oxide layers changes the color of the titanium as light is reflected between the inner and outer surfaces of the oxide layers.[29] Anodization thus seems to be a good solution to the aesthetic problems of titanium abutments. Although the efficiency of anodized-titanium with the use of peri-implant soft tissue have been studied in previous studies,[30,31] research on the use of anodized-titanium for restorations has been limited, especially with common dental ceramics, such as lithium disilicate. Therefore, understanding how the color of anodized-titanium affects the final color of lithium disilicate is important to successful use in aesthetic dental implant treatments.

The color can be quantitatively analyzed by a spectrophotometer, which can measure reflected light from the target object and express the color data in three coordinate values, L*, a* and b*. The three values are present in the three axes of CIE Lab space, and represent lightness, green-red chromaticity and blue-yellow chromaticity, respectively. Color difference (ΔE) of two objects can be calculated by an equation from differences between the values of L*, a* and b* of the two objects. A lower color difference means the two objects are of a similar color. In order to understand the color differences between the two objects, a decision criterion is needed to interpret the degree of color differences. The perceptibility threshold (PT) and the acceptability threshold (AT) are thresholds of color differences to distinguish the differences of two objects based on whether the differences are noticeable or acceptable, respectively. Color matches at or below the perceptibility threshold would be ideal, because achieving an absolute match is costly, time-consuming and frequently not essential.[32] Color differences below the acceptability threshold, referring to the color differences of the two objects being acceptable and no color correction being required, might be more useful than perceptibility threshold in clinical situations.

Accordingly, acceptability threshold levels were sought by numerous studies. One major study, which followed the international standard organization (ISO) and was designed as a multi-center study to include various nationalities and dental professions, stated that the acceptability threshold of 50% of observers is below 2.7 for CIE Lab system.[33]

The purpose of this study is to evaluate the esthetic outcomes via the color differences values of lithium disilicate ceramics on a foundation made of zirconia, untreated and anodized titanium. The thicknesses of the lithium disilicate ceramic and the voltage of anodized titanium were systematically varied. The null hypotheses evaluated were that both materials and ceramic thickness would not affect to the measured color differences.

MATERIALS AND METHODS

Lithium disilicate ceramics (IPS e.max CAD, Medium translucency, A1 shade) were prepared in order to make 28 ceramic CAD-CAM specimens. These were divided into four groups based on their thicknesses (1.0, 1.5, 2.0 and 2.5 mm) with seven disk-shaped (11 mm in diameter) specimens in each group. Based on the results of the author's unpublished pilot study, a sample size of 3 or more was recommended to achieve $\alpha = 0.05$ with the power of a test of more than 0.95. Accordingly, a sample size of 7 was used. The ceramic specimens were made by a computer-aided design and computer-aided manufacturing (CAD-CAM) system. A 3D-designing program (Tinkercad) was used to design the shape of the specimens. Lithium disilicate blocks were milled with a milling machine (MasterMill N4). One side of the specimens was ground with 600, 800, 1000 and 1200 abrasive disks on a sanding machine (Phoenix Beta) at 100 rpm for 15 seconds under water cooling. The thickness of the specimens was re-examined after grounding with a thickness gauge (Calipretto S). Firing procedures were processed according to the manufacturers' recommendation by a vacuum furnace (Programmatt P300). The specimens were not glazed to maintain their thicknesses.

Zirconia and titanium disc-shaped (11 mm in diameter, 2 mm thickness) specimens were fabricated to make the foundation. Seven zirconia (Zirkon Translucent) specimens were designed with the CAD-CAM system via the 3D-designing program (Tinkercad) and milled with a milling machine (Heavy Metal Milling unit). Thirty-five titanium (Titanium grade 5) specimens were cut from an 11 mm-diameter titanium bar with a low-speed precision sectioning cutter (Isomet 1000). All specimens were grounded with 600, 800, 1000 and 1200 abrasive disks on a sanding machine (Phoenix Beta) at 100 rpm for 15 seconds under water cooling. All specimens were cleaned in distilled water for 5 mins in an ultrasonic cleaner (Biosonic UC125H), and left to dry at room temperature.

Twenty-eight disk-shaped titanium specimens were colored via anodization at room temperature. They were divided into four groups (n=7 each) according to voltage. The anodization was achieved using a 1.96% (w/v) sodium bicarbonate solution as an electrolyte. The titanium disks were fixed onto an anode, and a 3 x 6 cm^2 stainless steel plate was fixed on a cathode. Voltages of 40 V to 70 V were supplied by a power supply (KPS1203D). Each 10 V increment resulted in a different color of specimen: blue (40 V-anodized titanium), light yellow (50 V-anodized titanium), yellow (60 V-anodized titanium) and pink (70 V-anodized titanium) *(Figure 1)*. The anodization was perfomed for 60 seconds. The specimens were subsequently cleaned in distilled water for 10 mins, dried at room temperature, and stored in a case before use.

The control for this experiment was made from an A2-dentin shade composite resin (Filtek Z350XT). The mold was fabricated by silicone putty (Silagum). A specimen was placed into the mold with incremental layering technique to reduce the shrinkage of the polymer. The specimen was illuminated over a glass slide for 20 seconds per layer by an LED curing light (LED P-Pen) with a soft start mode.

The foundation disks were placed on the custom-made aligning block. The ceramic specimens were optically connected to the foundation with three drops of glycerin (Glycerine; Refractive index=1.47). Three shades were measured with the same spectrophotometer (Vita EasyshadeV) by one operator. The spectrophotometer was measured on the center of a flat surface of the ceramic specimens through the hole of a black box that had a position aligned with those of the specimens inside, while color measurement, the spectrophotometer's tip can generate the light source itself and the black box was made to anti-light pollution. After taking measurements for three shades, the next ceramic specimens were then placed after 3-drop of glycerin on the foundation.

CIELab values (L*, a* and b*) were measured for all ceramic specimens and the foundation via simple random sampling, and an average of three measurements was recorded. Color differences (ΔE) values were calculated from the CIELab values of the tests and the control (with corresponding ceramic thickness). ΔE was calculated using the formula:

$$\Delta E - \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}.$$

A threshold value for clinical acceptability was set to 2.7 to interpret the color differences.

A statistical software (IBM SPSS statistics version 21.0) was used for data analysis. The Kolmogorov Smirnov test indicated a normal distribution of the data in all groups ($p>0.05$). Two-way ANOVA analysis was used to compare ΔE values among the groups, and ΔE values were evaluated considering ceramic thickness and foundation. Pairwise comparisons of the groups were performed using a post-hoc test. The t-test was used to compare ΔE values with clinical acceptability threshold ($\Delta E<2.7$). ($\alpha=0.05$ for all tests)

Figure 1: Untreated titanium, 40 V (blue), 50 V (light yellow), 60 V (yellow) and 70 V (pink) anodized titanium (from left to right).

RESULTS

Results from the 2-way ANOVA analysis showed that the ceramic thickness, the foundation as well as the interaction between the two factors significantly affected the mean values of color differences (ΔE) of lithium disilicate ceramic ($p<0.05$) *(Table 1)*.

The mean values of each CIE values (L, a and b) of composite resin (control) tend to be greenish and bluish according to the increase of the ceramic thickness, while lightness would vary in the range of 83.95-85.79, as shown in Table 2. The mean values of each CIE values (ΔL, Δa and Δb) and ΔE were compared to the control, as shown in Figure 2, 3, 4 and Table 3, respectively. It is to note that it was not possible to obtain the values for 1-mm ceramic thickness and 40 V-anodized titanium due to the limited capability of the instruments. The mean values of ΔE of the specimens with four different ceramic thickness (1.0, 1.5, 2.0 and 2.5 mm) were significantly different. As the ceramic thickness increased, the mean values of ΔE decreased *(Table 3, Figure 5)*. The mean value of ΔE was the lowest for the 60 V-anodized titanium (ΔE = 4.76), followed by the 50 V-anodized titanium (ΔE = 4.86). However, the difference in the mean value of ΔE of 60 V-anodized titanium was not significant from that of 50 V-anodized titanium. The highest mean value of ΔE was found at the 70 V-anodized titanium (ΔE =10.73). When considering the ceramic thickness, the lowest mean value of ΔE for the 50 V-anodized titanium was found at the thickness of 1 mm whereas that for the 60 V-anodized titanium was found at the thickness of 1.5 mm. For the specimens with zirconia, the lowest mean values of ΔE occurred at the thickness of 2.0 mm or above.

The mean values of ΔE from the specimens with different foundation and ceramic thickness were evaluated to the clinical acceptability threshold value (ΔE<2.7). It was found that all foundation with 1.0-mm and 1.5-mm ceramic thickness gave mean values of ΔE above the acceptability thresholds. However, when ceramic thickness of 2.0 mm was considered, the mean values of ΔE were found to be below the clinical acceptability threshold for the zirconia-based foundation. At a ceramic thickness of 2.5 mm, the mean value of ΔE were below the clinical acceptability for zirconia, 50 V-anodized titanium and 60 V-anodized titanium *(Figure 5)*.

DISCUSSION

The purpose of this study was to apply lithium disilicate ceramic onto implant abutments in a simulated clinical setting, with the goal of achieving superior esthetics by managing two major factors to reduce the gap of color difference between restorative materials and natural teeth. Based on the results of this study, ceramic thickness and abutment modifications significantly affect the mean value of color differences and accordingly the null hypothesis was rejected.

Over the years, several studies have sought to define acceptability threshold levels for such use. In 2007, Douglas *et al.*[34] did a clinical assessment using acrylic resin teeth of

Table 1. Results of a two-way ANOVA for mean ΔE values of combinations (foundation and ceramic thickness) tested.

Source	*df*	Sum of Squares	Mean Square	F	P
Ceramic thickness	3	1428.67	476.22	6703.50	<.05*
Foundation	5	1115.60	223.12	3140.72	<.05*
Interaction	14	172.81	12.34	173.75	<.05*
Error	138	9.80	0.07		
Total	161	10399.67			

Table 2. Mean values of L, a and b of different ceramic thickness on composite resin (control group).

Ceramic thickness (mm)	**1.0**			**1.5**			**2.0**			**2.5**		
Foundation	**L**	**a**	**b**	**L**	**a**	**b**	**L**	**a**	**b**	**L**	**a**	**b**
Composite resin (control)	84.05+0.49	-1.14+0.10	16.42+0.29	83.95+0.63	-1.41+0.09	15.08+0.30	85.79+0.88	-1.56+0.08	14.66+0.39	84.49+0.20	-1.68+0.10	14.19+0.32

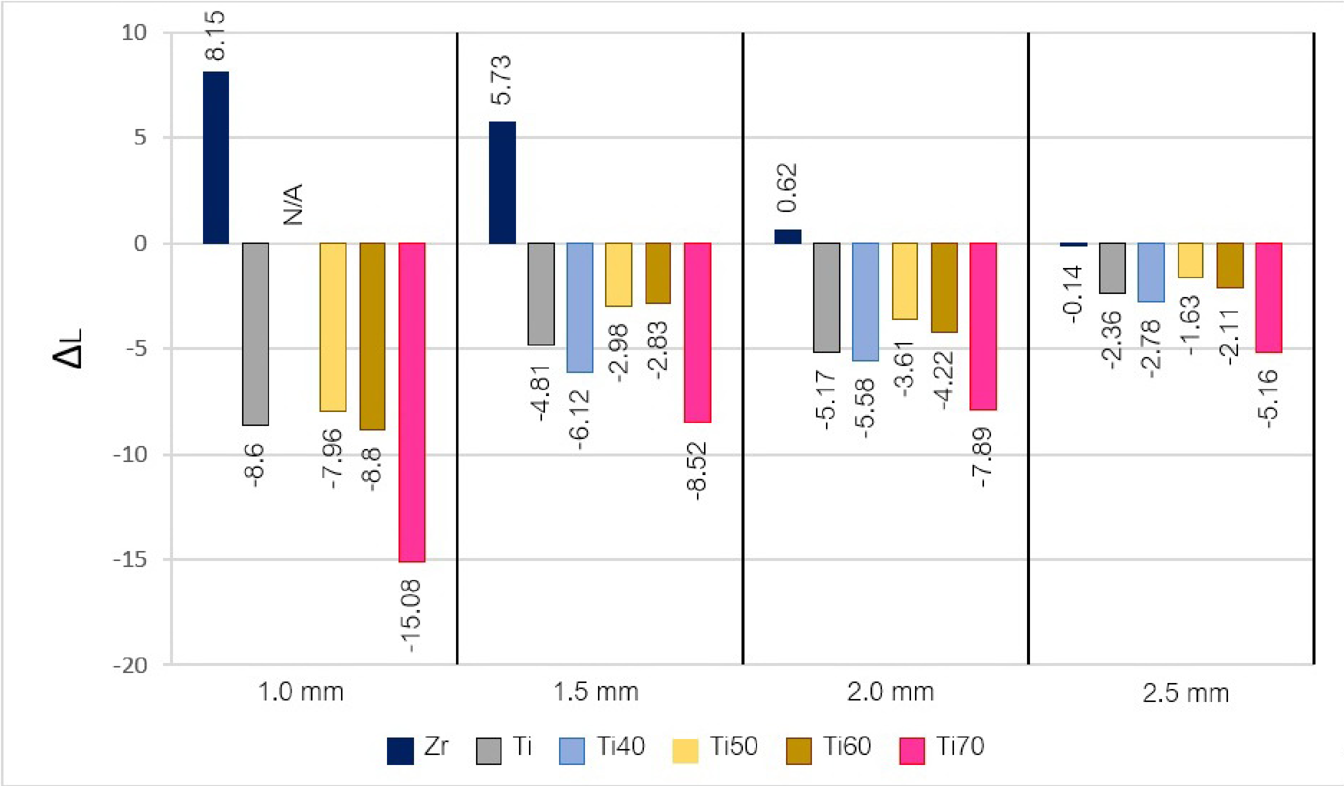

Figure 2: Bar graph of lightness changes (defined by ΔL*) with different foundation materials and ceramic thickness.

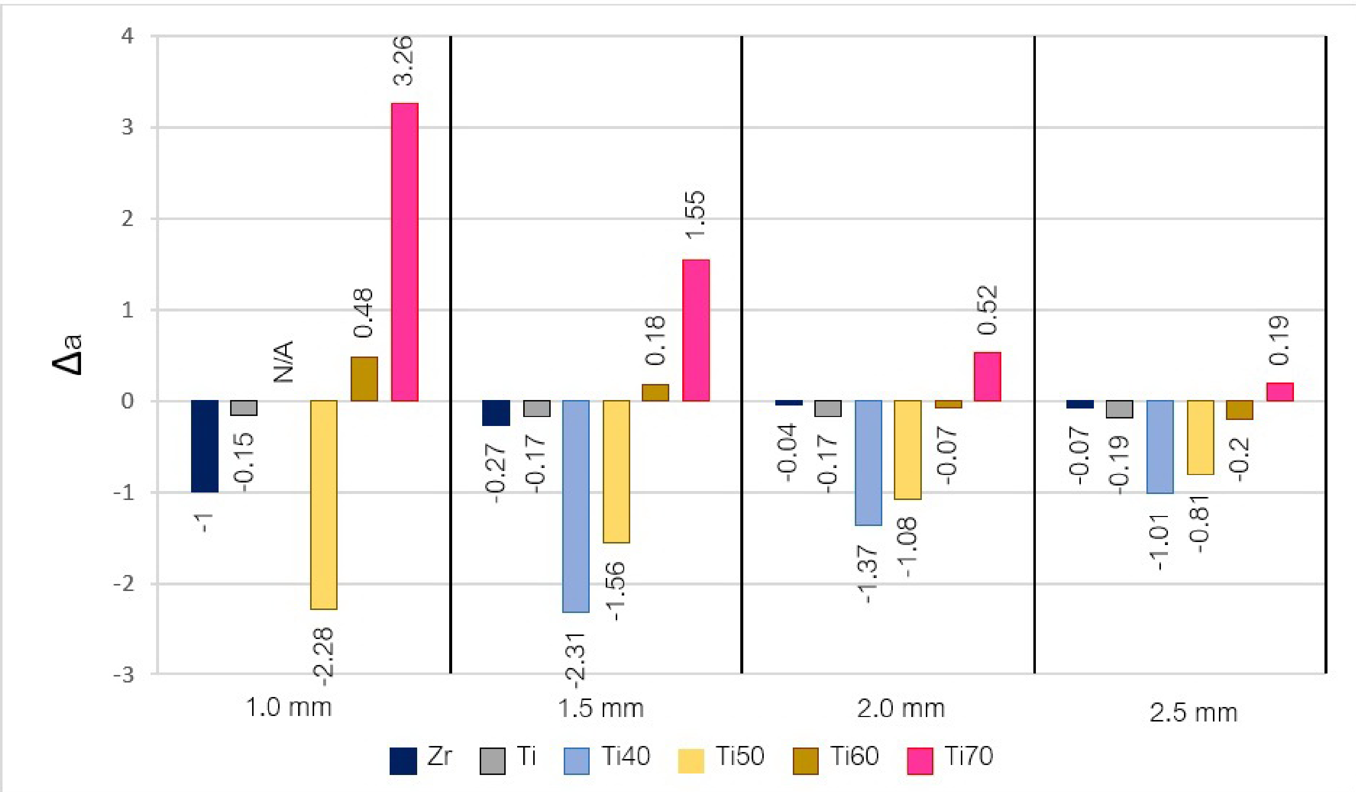

Figure 3: Bar graph of chromaticity changes (defined by Δa*(red-green values)) with different foundation materials and ceramic thickness.

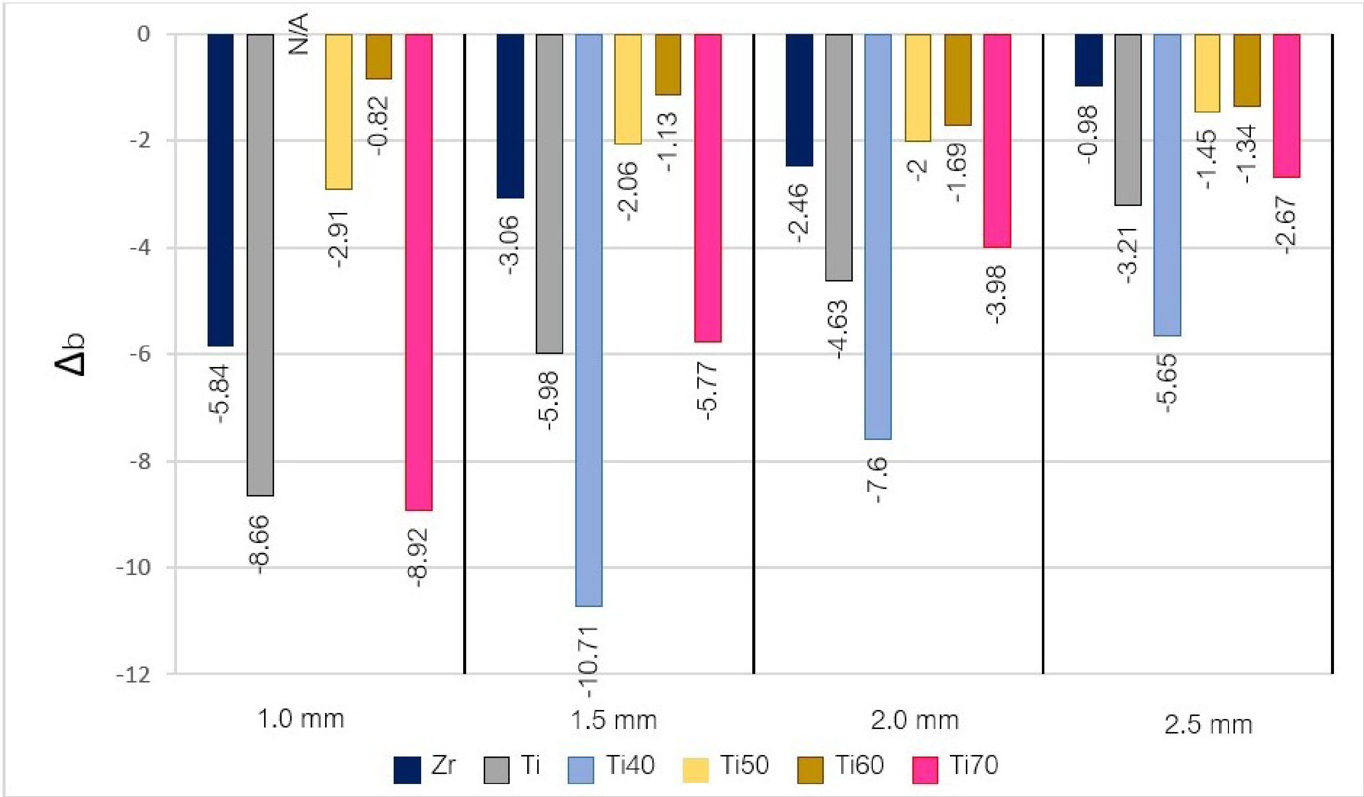

Figure 4: Bar graph of chromaticity changes (defined by Δb*(blue-yellow values)) with different foundation materials and ceramic thickness.

Table 3. Mean ΔE±SD of specimen assemblies with different ceramic thickness and foundation.

Ceramic thickness (mm) Foundation	1.0	1.5	2.0	2.5	Estimate mean
Zirconia	10.08±0.51	6.51±0.44	2.53±0.23*	1.07±0.07*	5.05[a]
Titanium	12.21±0.17	7.68±0.11	6.96±0.30	4.01±0.14	7.71[b]
40 V anodized titanium	N/A	12.56±0.23	9.53±0.11	6.38±0.09	9.49[c]
50 V anodized titanium	8.79±0.20	3.96±0.24	4.29±0.16	2.37±0.25*	4.86[d]
60 V anodized titanium	8.87±0.26	3.08±0.43	4.56±0.18	2.53±0.22*	4.76[d]
70 V anodized titanium	17.83±0.56	10.41±0.13	8.85±0.13	5.82±0.18	10.73[e]
Estimate mean	11.56[A]	7.37[B]	6.12[C]	3.70[D]	

varying shade mismatch. 28 dental practitioners determined the differences between the specimens and natural teeth, comparing to values of color measurements. The results of this study showed that the acceptability threshold for 50% of observers was 5.6 ΔE_{ab} units. In 2012, an *in vitro* study, pursued by Alghazali *et al.*,[35] determined an acceptability threshold by comparing specimen pairs of maxillary central incisors denture teeth in a phantom head. A total of 80 observers, divided into four groups (dentists, dental assistants, technicians and researchers), were included in the study. The acceptability threshold for 50% observers was 4.2 ΔE_{ab} units. In 2015, a multi-center study by Paravina *et al.*[33] was published to further investigate acceptability threshold levels. 175 observers were involved at seven different sites on four continents: 25 observers per site divided into five groups; dentists, dental students, dental technicians, auxiliaries and lay persons. All observers were asked to provide visual judgements on 60 pairs of ceramic specimens. The mean value of 50% observers indicated the acceptability threshold to be 2.7ΔE_{ab} units.

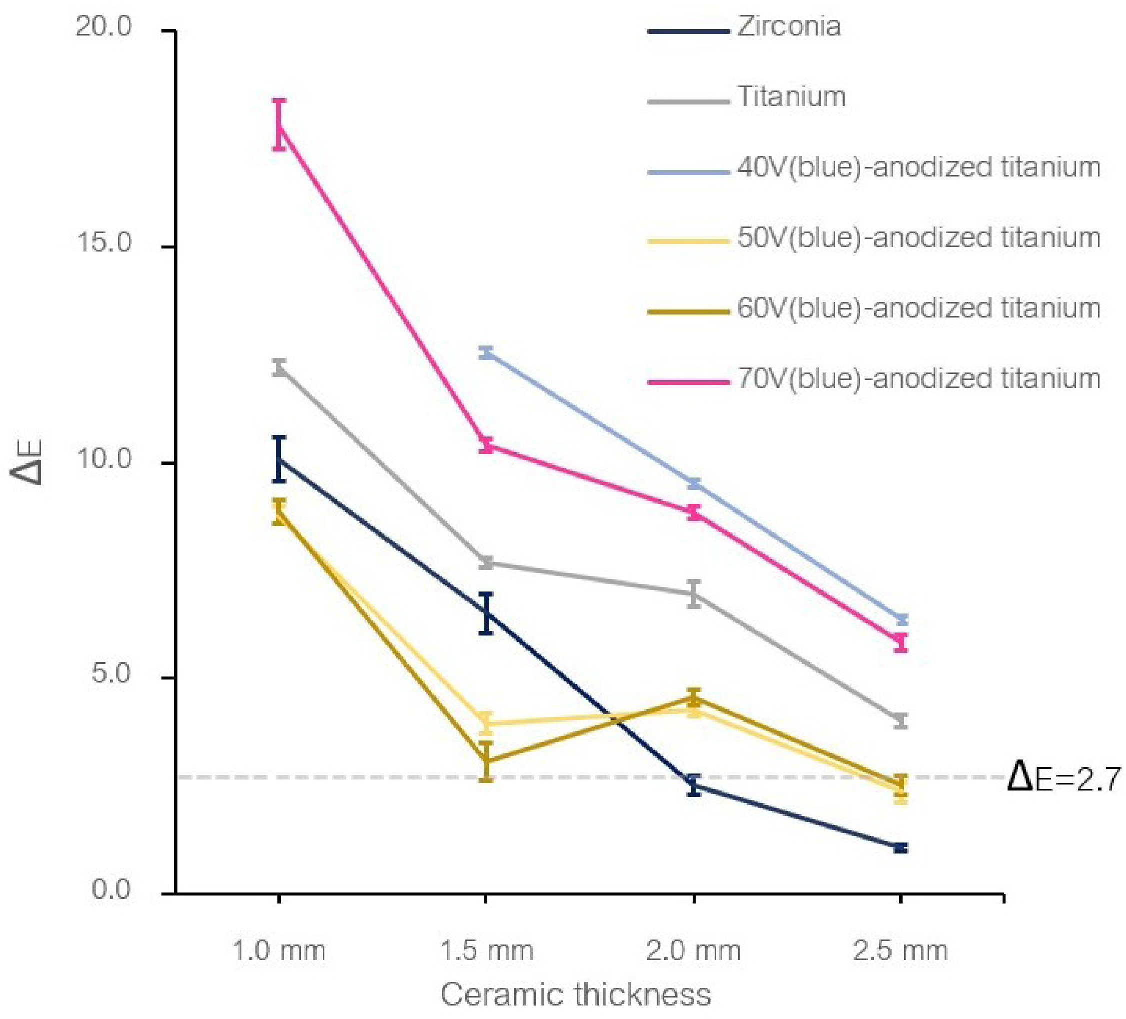

Figure 5: Box plot of mean ΔE±SD from combination of different ceramic thickness and different foundation restoration materials.

Several studies have demonstrated the importance of increasing ceramic thickness to mask the darker foundations and to achieve an aesthetics outcome.[10,36,37] Similar to the conclusions of this study, the mean values of color differences decreased as ceramic thickness was increased for all foundations. As emphasized by the previous study,[11] while the masking ability of increasing ceramic thickness can produce greater opacity in materials, this ability is different among the ceramic systems, depending on the optical properties of the material itself. The opaquer ceramic systems would permit a lower amount of light through the materials.[2,3,11] Most of these occur in higher strength ceramic systems because they are reinforced by more crystalline content which is opaquer as well. However, the application of high opacity ceramic systems, such as alumina or zirconia, often limits their use as core materials, especially in the esthetics zone. This is due to their need for the translucency of restorations to make them esthetically pleasing, which is achieved by the sufficient thickness of the veneering porcelain.[2,3,38]

Although increasing ceramic thickness can mask the foundation,[10,36,37] the results of this study show that the increase of the lithium disilicate ceramic (medium translucency) thickness cannot be limited to the influence of the foundation. Increasing ceramic thickness to 2.5 mm is not sufficient to mask the color of three foundation (Titanium, 40 V (blue) and 70 V (pink)-anodized titanium) to be lower than color acceptability (ΔE<2.7). In support of the results of previous studies,[8] this study confirmed that the effect of foundation influence on the color differences of lithium disilicate ceramics, as well as that highly translucent ceramics cannot limit the influence of undesirable foundation color by increasing ceramic thickness only.

Based on the results of this study, the color differences of zirconia were the lowest and lower than clinical acceptability (ΔE<2.7) for 2.0 and 2.5 mm-ceramic thickness. Numerous studies[19,20] support that a zirconia foundation shows the lowest color differences, relative to titanium or gold-colored foundations. The optical properties of zirconia seem to be the important factor to close the gap to natural tooth's color in restorations because its translucency allows slight light transmission. This is similar to the natural phenomenon in human dentine.[11,19,39] Moreover, previous studies[39] demonstrate that zirconia could satisfactorily replace the human dentine as the restoring material in terms of translucency. However, the whiter appearance of zirconia remains a challenge for color matching because there are considerable color differences from the human dentine and thus one needs to carefully adjust the color to produce a clinically acceptable color matching.

The results of this study showed that 50 V and 60 V-anodized titanium, which provided light yellow and yellow respectively, showed lower color differences than untreated titanium for all ceramic thickness. And, they were lower than clinical acceptability (ΔE<2.7) for 2.5 mm-ceramic thickness. Although the anodization process of this study cannot provide the gold-shade titanium, the results of yellow-shade titanium tend to replicate the results of gold-shaded materials from previous studies. Those indicated that gold abutments showed a lower color difference than titanium abutments and more than zirconia abutments for clinical and laboratory study, because their color is better than titanium but their translucency is worse than zirconia.[19,20] Furthermore, the results of this study showed that the yellow-shade of anodized titanium showed a better ΔL than the other titanium specimens and a better Δb than the other specimens. These correspond to Stevenson *et al*. study,[40] which demonstrated that gold-shade materials were lighter or had larger L* values and provided more yellow or greater b* values than other metal shades. The lighter appearance corresponds to the human dentine, which allows some light through itself. And, the yellowish color corresponds to the main color of the human dentine that shines through enamel.[41-43] Therefore, when applied with the ceramic materials, those allow gold-shade materials to achieve better color matchings than the other metal shades.[40,42]

Although 50 V and 60 V-anodized titanium showed the lowest color differences for all foundation, including zirconia for less than 1.5 mm-ceramic thickness, they showed more than zirconia for greater than 2.0 mm-ceramic thickness. This phenomenon could be explained by two reasons: the influence of ceramic thickness and the color of materials. For the influence of ceramic thickness, Volpato *et al.*[44] demonstrated that the influence of thinner thickness could not overcome the influence of the foundation because the crystalline particles in these thicknesses are not enough to mask the foundation. Whereas, in thicker thicknesses, they could be opaquer and overcome the influence of the foundation due to greater crystalline particles. If influence of the foundation is greater than influence of ceramic thickness at thinner thickness, it could be assumed that 50 V and 60 V-anodized titanium might offer a better color or hue than zirconia. Niu *et al.*,[37] who compared colors of lithium disilicate ceramic over three materials consisting of silver-palladium alloy, gold alloy and white opaque composite resin, indicated that white opaque composite resin showed the greatest color differences. Whereas, gold alloy showed the smallest color differences. Since the present study focuses only on the color, zirconia, that has the white appearance similar to white opaque composite resin in Niu *et al.*'s study, should offer worse color differences than 50 V and 60 V-anodized titanium. However, this is not the case because zirconia offers better translucency than titanium or anodized titanium. These support the argument that zirconia in situations of thicker ceramic thickness (lower the foundation influence) offers better color differences than opaque titanium.

The results of this study show that anodization of titanium to yellow-shade alloys can improve the color of lithium disilicate ceramics with adequate ceramic thickness. Moreover, the previous study showed that gold-anodized titanium presented lower color differences with peri-implant soft tissue than untreated titanium, and approximate values to pink-anodized titanium[30,31] showed that(pink-anodized titanium) presented worse color differences of ceramic according to this study. Although it cannot compare to zirconia, which showed the least color differences, in term of translucency, the yellow-shade of anodized titanium in thinner than 1.5 mm ceramic thickness seem to be a more suitable choice than zirconia, but it nevertheless remains higher than color acceptability. The other factors, such as ceramic translucency, cement color and cement thickness, should also be considered to achieve esthetic outcomes. Further studies should investigate on other correlatable factors.

CONCLUSIONS

Within the limitations of this study, it was concluded that both ceramic thickness and the foundation significantly affect the final color of lithium disilicate restorations. The color differences decrease when ceramic thickness is increased for all foundations. The color differences of lithium disilicate ceramic on yellow-shade (50 V and 60 V) of anodized titanium are efficient to improve the grayish appearance of titanium. And, zirconia and yellow-shade of anodized titanium tend to achieve esthetics outcome in combination with adequate ceramic thickness.

ACKNOWLEDGEMENTS

Funding source: Faculty of Dentistry, Srinakharinwirot university

CONFLICT OF INTEREST

The author reported no conflict of interest.

MANUFACTURERS DETAILS

- Lithium disilicate ceramics (IPS e.max CAD, Medium translucency, A1 shade, Ivoclar Vivadent, Leichtenstein)
- 3D-designing program (Tinkercad, Autodesk, USA)
- Lithium disilicate ceramic milling machine (MasterMill N4, VHF, Germany)
- Sanding machine (Phoenix Beta, Buehler, USA)
- Thickness gauge (Calipretto S, Renfert, Germany)

- Vacuum furnace (Programmatt P300, Ivoclar Vivadent)
- Zirconia (Zirkon Translucent, Zirkonzahn, Italy)
- Zirconia milling machine (Heavy Metal Milling unit, Zirkonzahn)
- Titanium (Titanium grade 5, Baoji Seabird Metal Material, China)
- Low-speed precision sectioning cutter (Isomet 1000, Buehler)
- Ultrasonic cleaner (Biosonic UC125H, Caltene/Whaldent, USA)
- Power supply (KPS1203D, Wanptek, China)
- Composite resin (Filtek Z350XT, 3M ESPE, USA)
- Silicone putty (Silagum, DMG, Germany)
- LED curing light (LED P-Pen, Vector, USA)
- Glycerin (Glycerine, Refractive index=1.47, Krungthepchemi, Thailand)
- Spectrophotometer (Vita EasysadeV, Vita, Germany)

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