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Effect of Different Color Anodization of Titanium on Resulting Shade of Lithium Disilicate

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DEDICATION

A special thanks to my wife, CPT Ciara Chen who helped me through my time as a resident and the completion of this manuscript. Another special thanks to my cats, Felix and Nangua for their emotion support during th writing of this manuscript.

ABSTRACT

Purpose: The purpose of this study is to determine if there is a color titanium implant abutments can be anodized to minimize the change in color of overlying lithium disilicate (LDS) crowns. Two different translucencies of LDS were tested to determine if translucency affects which color anodization achieves the best shade match.

Materials and Methods: Six titanium abutments were milled and polished. One abutment was left unanodized, while the other five were anodized at 11V, 31V, 54V, 64V, and 76V to result in a bronze, blue, green, yellow, and pink color respectively. Crowns were designed with 1mm of material thickness over the measured surface. Twenty sample crowns were milled from both IPS e.max CAD LT and MT to result in 40 total crowns. The differences in color, ΔE, was determined for each of the colored abutments with a spectrophotometer. A two-way ANOVA was used to assess if there was a statistically significant difference in shade due to titanium color and LDS translucency. A one-way t-test was performed on any combination with mean color differences below that of reported acceptability or perceptibility thresholds of 2.7 and 1.2 respectively.

Results: A two-way ANOVA was performed and a statistically significant difference was found with both the anodization color ($P=5.2\times10^{-147}$) and translucency ($P=1.08\times10^{-9}$). A Tukey's HSD was performed on the LT and MT groups separately to determine differences in the resulting shade from different colored abutments. In the MT samples, differences were found in the unanodized

and bronze, unanodized and blue, unanodized and pink, bronze and blue, bronze and green, bronze and yellow, bronze and pink, blue and green, blue and yellow, blue and pink, and green and pink pairings. In the LT samples, differences were found in all pairings besides the unanodized and green pairing. The yellow anodization with LT LDS resulted in a ΔE below the 50:50 acceptability threshold of 2.7 (P=0.024).

Conclusions: Differences were found in the shade when using 1mm thick lithium disilicate depending on both the translucency of the material used and the color of the abutment. Yellow anodization in combination with LT LDS was able to achieve a change in color below the acceptability threshold.

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INTRODUCTION

A dental implant is frequently the best option to restore an edentulous space, allowing for a fixed tooth replacement that leaves adjacent teeth untouched.[1] There has been an increased preference for using all ceramic restorations over the years due to their combination of strength and esthetics, as well as the shade consistency in milled ceramic materials.

The biggest challenge in restoring implants is fabricating a restoration that matches the adjacent dentition and seamlessly blends into its surroundings. In addition to creating proper restoration contours, shade matching is a key component in creating a restoration that does not stand out. Albert H. Munsell was the first to separate color into three distinct dimensions based on our ability to discern differences in colors. Munsell broke down a color into its three dimensions, hue, value, and chroma. Hue is the color of the light, determined by the wavelength at which the energy output of the light is greatest. Value is the brightness of the light, and chroma is the saturation or purity of the light. Munsell’s Color system allowed for clear communication of color by quantifying its three dimensions. Dental shade tabs utilize Munsell’s color system and an understanding of which can allow one to better describe the colors of teeth and restorations.[2]

Traditional shade matching involves holding up standardized shade guides against the dentition one is trying to match and relaying this subjective match to the dental lab. While this method works for many, it can be highly variable between clinicians. Utilizing quantitative instruments such as a spectrophotometer or colorimeter have proven to be a more dependable and reproducible method of color selection.[3,4]

Dental implants are often restored with titanium abutments, which can create an unnatural greying of the overlying ceramic restoration. One method clinicians and dental laboratories are utilizing to minimize the color change of titanium abutments is by anodizing it different colors.

REVIEW OF LITERATURE

In 1976, the Commission Internationale de l'Eclairge (CIE) created the CIELAB color space, which quantified colors into a point in three-dimensional space. The axes that describe a color's location within this space are L*, a* and b*. With instruments for color determination, the color coordinates of an object can be obtained and compared. The difference in color, ∆E, can then be calculated as the distance between two points within this color space and found with the following equation:

$$\Delta E_{ab}^{*} = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

The Vita Easyshade Advanced 4.0 is a dental spectrophotometer that allows for the measurement of the light reflected from objects to compute its coordinates in the CIE color space. In a study by Kim-Pusateri et al. the reliability and accuracy of color measurements from four dental shade matching instruments was compared. The Vita Easyshade was the only device with reliability and accuracy of over 90%.[5]

While spectrophotometers can detect miniscule differences in a theoretically infinite number of colors, these differences may not have any impact on the clinician. It is important to know at what ΔE does it become clinically impactful. The significance of color differences can be understood using acceptability and perceptibility thresholds. The difference in color which can be detected by half of the observers is the 50:50 perceptibility threshold. Likewise, the difference which is acceptable for half of the observers is the 50:50 acceptability threshold. The ΔE value as reported in the literature for these thresholds varies.[6] The most often cited ΔE_{ab} values for the 50:50 AT and PT thresholds are 2.7 and 1.2 respectively.[7]

Besides hue, value, and chroma, another property of teeth that is sometimes described as a fourth dimension of color is translucency.[8] Natural dentition has varying degrees of translucency, and this property must also be replicated to create restorations that blend in seamlessly with the surrounding dentition. All ceramic restorations come in varying degrees of translucency that can replicate a tooth's appearance, but this translucency can allow the underlying structure to show through and adversely affect the shade of the restoration. On natural teeth, this can be a discolored tooth or a cast post and core. In implant restorations, show through of titanium abutments can alter the perceived shade of the overlying restoration, and must be accounted for to achieve an acceptable color match. Chaiyabutr et al showed that tooth abutment color, cement shade, and restoration thickness all impact the resulting color of lithium disilicate crowns. They also found that opaque cement was not adequate in masking dark abutments with a minimal restoration thickness of 1.0 mm.[9]

A method of altering the color of titanium abutments to achieve a more favorable color is through the process of anodization. Altering the voltage used to anodize titanium creates an oxide layer of different thicknesses which allows the anodized titanium to generate a wide array of colors without the use of dyes.[10] A commonly used ceramic full contoured dental restoration is lithium disilicate. Lithium disilicate is often used as a monolithic restoration in the anterior region due to its high manufacturer reported biaxial flexural strength of over 500 MPa and its translucency. However, unanodized titanium will cause significant greying of lithium disilicate crowns, altering the resulting perceived color.

RESEARCH OBJECTIVES

The present study seeks to test six different colors of titanium abutments, unanodized, bronze, blue, green, yellow, and pink to determine if there is a color that minimizes the ΔE of shade A2 LDS. Additionally, two different translucencies of LDS will be tested, medium and low, to see if the different translucency alters which color the titanium should be anodized for a minimal shade change. The first null hypothesis is that the color of titanium will not cause a difference in the ΔE of the overlying LDS crowns. The second null hypothesis is that there are no differences in the benefits of specific color anodization with different translucencies of LDS.

MATERIALS AND METHODS

A titanium abutment was designed on 3Shape CAD software (3Shape, Copenhagen, Denmark) with flat buccal face for color acquisition. Mesial and distal seating grooves were placed to aid in orientation of crowns and to prevent frictional wear of the measurement surface. Lithium disilicate crowns were then designed over the custom abutments with 80µm of cement space and 1mm of material thickness over the measured surface on 3Shape.

Six titanium abutments were milled from Ti-6Al-4V blanks (dentaswiss, Biodenta, Berneck, Switzerland). The flat face used for color measurement was finished with Brownie and Greenie polishers (Shofu, Kyoto, Japan) at 7000 RPM and brought to a high shine with Zircon Brite polishing paste at 30,000 RPM (Dental Ventures of America, Corona, CA). One sample was finished at high polish to serve as the unanodized sample. The remaining five samples were anodized using a titanium color anodizer (Zirkonzahn Titanium Spectral-Colouring Anodizer, Zirkonzahn, Gais, Italy). Five grams of anodizing powder (Zirkonzahn, Gais, Italy) was added to 250mL of deionized water in a bottle and shaken to dissolve. This mixture was then poured into the anodizer container. The titanium abutment is then connected to the anode and completely submerged in the anodizing liquid. The titanium abutments were anodized at 13V, 31V, 54V, 64V, and 76V to achieve a bronze, dark blue, light green, yellow, and pink color respectively (Figure 1).

The designed crowns were milled 20 times in IPS e.max CAD MT A2 and IPS e.max CAD LT A2 (Ivoclar, Schaan, Liechtenstein) on the .MC X5 (Dentsply Sirona, Charlotte, NC) to result in 40 total crowns. Crowns were desprued and crystallized with the Programat EP 5010 (Ivoclar, Schaan, Liechtenstein). Following crystallization, the measured crown face was polished with Ceramaster points (Shofu, Kyoto, Japan) at 15,000 PRM, and finished to a high shine with

Zircon Brite polishing paste at 30,000 RPM (Dental Ventures of America, Corona, CA).

To ensure repeatable seating of the Vita Easyshade Advance 4.0 (VITA Zahnfabrik, Bad Sackingen, Germany), a clear acrylic jig was made over the sample. The acrylic jig was waxed up with baseplate wax (Henry Schein, Melville, NY) and the VITA Easyshade tip was used to create a circular cutout over the desired area of measurement. The wax-up was invested in laboratory condensation silicone (Coltene, Altstätten, Switzerland) and fabricated with the fluid pour method with ProBase Cold Clear (Ivoclar, Schaan, Liechtenstein). The acrylic was allowed to cure in a pressure pot for 20 minutes. The acrylic jig was smoothed with acrylic burs and finished on a lathe with pumice and polish. A hole was made on the acrylic jig over the occlusal of the crown to allow for verification of the complete seating of the jig (Figure 2).

All color measurements were made in a dark room with the sole light source being the laptop screen used to record the color coordinates. Prior to sample gathering, the Vita Easyshade was calibrated. The spectrophotometer was recalibrated after every 15 readings. Each sample was measured with the acrylic jig with no underlying abutment to obtain a control L*, a*, b* from which ΔE will be calculated for the different titanium abutments. Color measurements were taken three times for each sample and averaged.

Following recording of initial shade, each sample was placed over the six different titanium abutments. Calibra translucent try-in paste (Dentsply Sirona, Charlotte, NC) was used for each sample over each titanium abutment. L*, a*, b* coordinates were recorded three times for each sample with each of the six abutments. ΔE_{ab} was calculated using the average coordinates of the initial recording of the sample without an abutment with the average coordinates obtained overlying each of the six abutments.

A two-way ANOVA was performed on Microsoft Excel to analyze differences between the translucency of the LDS and the color of the titanium abutment. A Tukey HSD was performed post hoc to determine which groups were statistically different from each other. A one-way t-test will be performed on any combination which yields an average ΔE below either the acceptability threshold of 2.7 or the perceptibility threshold of 1.2.

RESULTS

The mean ΔE for the LT group was 2.93 for unanodized titanium, 5.73 for the bronze, 9.44 for the blue, 3.11 for green, 2.35 for yellow, and 3.70 for pink. The mean ΔE for the MT group was 3.12 for unanodized titanium, 6.15 for the bronze, 9.98 for the blue, 3.24 for green, 3.36 for yellow, and 3.94 for pink (Table 1) (Graph 1).

A two-way ANOVA revealed a difference between the two translucency groups, LT and MT with a $P=1.08x10^{-9}$. It also revealed a difference attributed to the color of the titanium, with a $P=5.3x10^{-147}$ and an interaction between the translucency and titanium color with $P=6.55x10^{-5}$ (Table 2). A Tukey HSD at an $\alpha=0.05$ was performed for the MT and LT groups. Within the MT samples, there was a difference between the unanodized and bronze, unanodized and blue, unanodized and pink, bronze and blue, bronze and green, bronze and yellow, bronze and pink, blue and green, blue and yellow, blue and pink, and green and pink pairings. Within the LT samples, there was a difference between the unanodized and bronze, unanodized and blue, unanodized and yellow, unanodized and pink, bronze and blue, bronze and green, bronze and yellow, bronze and pink, blue and green, blue and yellow, blue and pink, green and yellow, green and pink, and yellow and pink pairings (Table 3).

To see if any of the tested combinations of translucency and titanium color was statistically significantly lower than the 50:50 acceptability threshold for ΔE_{ab} of 2.7, a one tailed t-test for mean was performed on any combination with a mean ΔE lower than the threshold. As the only combination with a mean that is below the acceptability threshold of 2.7 was the LT LDS overlying the yellow anodized abutment, a one tailed t-test revealed that the mean ΔE of 2.35 was statistically significantly lower than the AT (2.7) with P=0.024.

DISCUSSION

In this study, we examined the effects of different color anodization and their resulting color change on overlying translucent dental ceramics. We wanted to test several colors that are not commonly used to try and see if the colors traditionally used result in the best color match of the overlying crown. In this study we also looked to elucidate the effect that different translucencies can have on the optimal color to anodize titanium.

Based on the results of this study, the null hypothesis that anodizing titanium abutments different colors will not have an effect on the resulting shade can be rejected ($P=5.3\times10^{-147}$). However, there is not enough evidence to reject the second null hypothesis that the translucency of the ceramic material will not make a difference on the effect of titanium color on the resulting shade. While the ascending order of the average ΔE in the MT group differs from that of the LT group, the differences between the unanodized, green, and yellow abutments were not significantly different within the MT group.

In terms of achieving a successful dental restoration, it must satisfy both functional and esthetic demands of the patient. An unsuccessful color match is wasted time and resources for both the patient and clinician. While achieving an imperceptible shade difference in our restorations is ideal, it is often not worth the time and resources to achieve. As such, the acceptability threshold is of more clinical significance.[6] In this study, when looking to see if there was a color titanium could be anodized for 1mm thick LT or MT LDS to achieve an acceptable shade difference, it was found that LT LDS with yellow anodization could achieve a ΔE below 2.7 (P= 0.024). No other combination tested resulted in a ΔE that half of the population could be expected to find acceptable. This result suggests that when using anything other than LT LDS with yellow anodization, one cannot expect to achieve an acceptable shade match through anodization alone. Scenarios where one would consider using something other than yellow anodization is in cases where there is thin facial gingiva, and the titanium abutment can negatively impact the gingival color. In those cases, one should consider other methods to achieve an adequate shade match, such as increasing the material thickness or using an opacious cement.

Recent studies published in 2022 looked at different combinations of ceramic thickness and titanium anodization on the resulting shade and how they relate to acceptability thresholds. In one study comparing yellow anodized with unanodized titanium with different thicknesses of high translucency LDS, they found that yellow anodization achieved a lower ΔE compared to unanodized titanium and 2mm thick LDS achieved a lower ΔE than 1mm thick LDS. They also found that neither the yellow or unanodized group were able to clear the acceptability threshold at 1mm thickness, but both were able to do so at a 2mm thickness.[11] Another study looked at 1.0, 1.5, 2.0, and 2.5mm thick medium translucency LDS against a backing of zirconia, unanodized titanium, blue, light yellow, yellow, and pink anodized titanium. They found that both the material thickness and background material have a significant effect on the resulting shade of the restoration. To achieve an acceptable color match with zirconia, 2mm thickness of LDS was required, and for an acceptable shade with the light yellow and yellow anodized titanium, 2.5mm of LDS was required.[12]

When selecting a material for implant abutments, there are two primary options in contemporary dentistry, namely titanium and zirconia. Comparing the two, generally you are trading esthetics for more control over the emergence profile and mechanical properties when choosing titanium, and vice versa. Zirconia abutments on titanium implants still must rely on a titanium base for a stable implant-abutment interface. This can cause limitation in the emergence profile as the emergence of the base cannot be altered, and one must concern themselves with minimum thicknesses at the base of the zirconia abutment.

Zirconia abutments are also brittle and lack the toughness of titanium abutments, which can make them more prone to fracture. The upside to zirconia abutments is that they are more esthetic, especially in thin gingival phenotypes. When gingival thickness is less than 3mm, a titanium abutment will cause noticeable discoloration in the gingiva and negatively impact the pink esthetic score, even when anodized pink.[13,14] While pink anodization has been advocated to help improve the pink esthetic score, this study and others have shown that pink anodization is not very beneficial to the white esthetic score of the implant restoration.[12] More recently, a split mouth study looking into the benefits of pink anodization on peri-implant soft tissue appearance have found no esthetic benefit of pink anodization over unanodized titanium.[15]

Given the results of this and other similar studies, titanium implant abutments should be anodized yellow to achieve the best possible color match. However, this by itself is often not enough to ensure an adequate color match at minimal thicknesses of a translucent material. It is therefore recommended when trying to shade match in an esthetically important area with a titanium abutment to anodize the abutment yellow, consider opaquing the abutment, use as opaque of a crown material as esthetically allowable, have the abutment and crown designed to allow for as thick of a restorative material as possible, and to use opacious cement to lute the restoration.

CONCLUSIONS

Within the limitation of this study, it can be concluded that there is a difference in the resulting shade depending on the color an abutment is anodized, with yellow appearing to be the best color for LT LDS. At 1mm thickness, a low translucency LDS with a yellow anodized titanium abutment can achieve a clinically acceptable shade.

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TABLES

	ΔE ti	ΔE bronze	ΔE blue	ΔE green	ΔE yellow	ΔE pink
LT						
Average	2.93	5.73	9.44	3.11	2.35	3.70
Variance	0.10	0.30	0.64	0.22	0.56	0.44
Standard Deviation	0.31	0.53	0.78	0.46	0.73	0.65
MT						
Average	3.12	6.15	9.98	3.24	3.63	3.94
Variance	0.14	0.74	0.43	0.08	0.11	0.09

Table 1: Average, Variance, and Standard Deviation of ΔE

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Translucency of crown	12.99849	1	12.9984911	40.4615941	1.08483E-09	3.88257
Color of titanium	1418.294	5	283.658897	882.971035	5.338E-147	2.25364
Interaction between translucency and titanium color	9.034798	5	1.80695959	5.62468865	6.54875E-05	2.25364
Within	73.24615	228	0.32125504			
Total	1513.574	239				

Table 2: Two-way ANOVA

Comparison	MT	LT
ti vs bronze	means are significantly different	means are significantly different
ti vs blue	means are significantly different	means are significantly different
ti vs green	means are not significantly different	means are not significantly different
ti vs yellow	means are not significantly different	means are significantly different
ti vs pink	means are significantly different	means are significantly different
bronze vs blue	means are significantly different	means are significantly different
bronze vs green	means are significantly different	means are significantly different
bronze vs yellow	means are significantly different	means are significantly different
bronze vs pink	means are significantly different	means are significantly different
blue vs green	means are significantly different	means are significantly different
blue vs yellow	means are significantly different	means are significantly different
blue vs pink	means are significantly different	means are significantly different
green vs yellow	means are not significantly different	means are significantly different
green vs pink	means are significantly different	means are significantly different
yellow vs pink	means are not significantly different	means are significantly different

Table 3: Tukey's HSD results showing groups with significantly different means

GRAPHS

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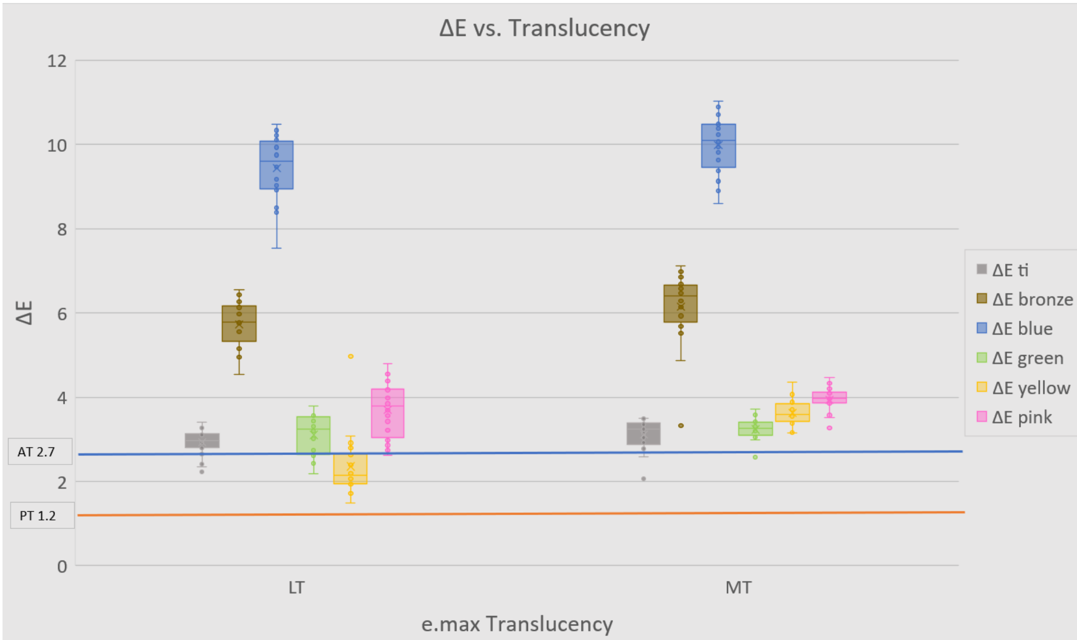

Graph 1: Box and Whisker plots of ΔE with superimposed AT and PT lines

FIGURES

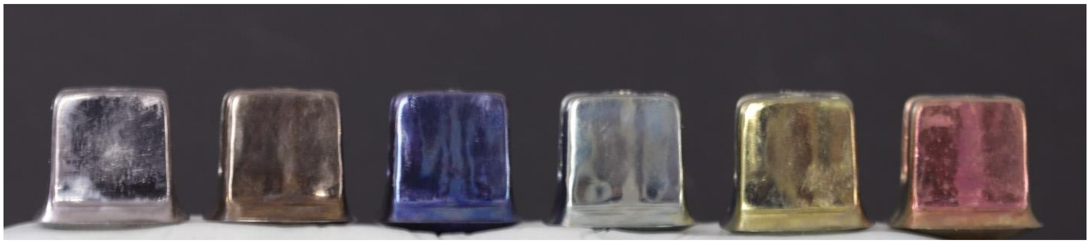

Figure 1: Titanium custom abutments (from left to right): unanodized, bronze, dark blue, light green, yellow, pink

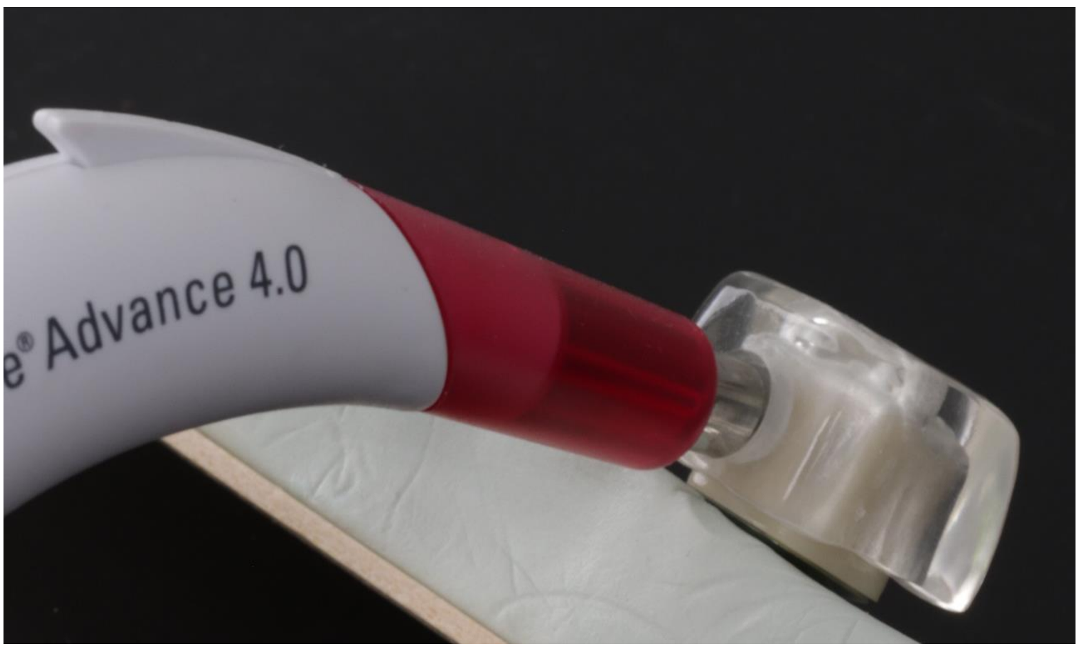

Figure 2: Clear Acrylic jig for orienting spectrophotometer during color measurement