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# UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES

POSTGRADUATE DENTAL COLLEGE  
NAVAL POSTGRADUATE DENTAL SCHOOL  
8955 WOOD ROAD  
BETHESDA, MARYLAND 20889



## THESIS APPROVAL PAGE FOR MASTER OF SCIENCE IN ORAL BIOLOGY

Title of Thesis: Determining Shade-matching and Blending Capabilities of a  
New Universal Dental Composite: An *in vivo* Study

Name of Candidate: Thuyvi Amy Truong  
Master of Science Degree  
June 01, 2022

THESIS/MANUSCRIPT APPROVED:

DATE:

HAMLIN.NICHOLAS.  
JAMES.1283653362

Digitally signed by  
HAMLIN.NICHOLAS.JAMES.128  
3653362  
Date: 2022.06.01 12:35:34 -04'00'

6/1/22

Nicholas J. Hamlin  
ASSOCIATE DEAN, NAVAL POSTGRADUATE DENTAL SCHOOL  
Committee Chairperson

ADCOOK.RICHARD.  
SCOTT.1027397375

Digitally signed by  
ADCOOK.RICHARD.SCOTT.102  
7397375  
Date: 2022.06.01 12:10:53 -04'00'

6/1/22

Richard S. Adcook  
CHAIRMAN, OPERATIVE DENTISTRY DEPARTMENT, NAVAL POSTGRADUATE DENTAL SCHOOL  
Committee Member

LUU.THU.NHUA  
N.1186011224

Digitally signed by  
LUU.THU.NHUAN.1186011224  
Date: 2022.06.01 11:58:03 -04'00'

6/1/22

Thu N. Luu  
COMPREHENSIVE DENTISTRY DEPARTMENT, NAVAL POSTGRADUATE DENTAL SCHOOL  
Committee Member

AVILLO.ANDREW.J  
AMES.1039513079

Digitally signed by  
AVILLO.ANDREW.JAMES.10395  
13079  
Date: 2022.06.01 12:01:27 -04'00'

6/1/22

Andrew J. Avillo  
CHIEF, PRIMARY CARE DENTISTRY, WALTER REED NATIONAL MILITARY MEDICAL CENTER  
Committee Member

DETERMINING SHADE-MATCHING AND BLENDING CAPABILITITES OF A  
NEW UNIVERSAL DENTAL COMPOSITE: AN IN VIVO STUDY

by

Thuyvi Amy Truong  
LCDR, Dental Corps  
United States Navy

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## ABSTRACT

Determining shade-matching and blending capabilities of a new universal dental composite: An in vivo study

Thuyvi Amy Truong, DMD, MPH, 2022

Thesis directed by: Nicholas Hamlin, PhD, DDS, MS, Associate Dean, NPDS

Demand for direct esthetic restorations is high and shade matching can be challenging. Newly developed universal composites claim to match all Vita Classical shades with a single product, eliminating the challenges of subjective shade matching. The purpose of this study was to quantify a universal composite's shade matching and blending capabilities as an in vivo direct veneer. Consented subjects (n=10) with an unrestored, non-carious left maxillary central incisor were enrolled into the study. For each subject, a direct spectrophotometric measurement (CIE L\*a\*b\*) was made of the natural tooth, followed by measurement of the cured universal composite on the tooth. A digital photograph with the composite in place was taken. A colorimeter application was used to obtain L\*a\*b\* values from the photographs at the composite's most incisal and cervical edges, as well as immediately adjacent to the composite on natural tooth structure.  $\Delta E_{00}$  were determined for the composite's ability to match the tooth shade beneath it ( $\Delta E_m$ ), and the composite's ability to blend with the incisal ( $\Delta E_i$ ) and cervical

( $\Delta E_c$ ) natural tooth shade immediately adjacent.  $\Delta E_{00} \leq 1.8$  was set as the acceptability threshold. The means for  $\Delta E_m$ ,  $\Delta E_i$ , and  $\Delta E_c$  were calculated. An independent *t*-test was used to compare the differences between  $\Delta E_i$  and  $\Delta E_c$ . The mean (standard deviation)  $\Delta E_{00}$  values were 6.16 (2.38), 3.90 (2.47), and 6.84 (1.80) for  $\Delta E_m$ ,  $\Delta E_i$ , and  $\Delta E_c$ , respectively. In comparing the differences in the means using the independent *t*-test between  $\Delta E_i$  and  $\Delta E_c$ , a statistically significant difference was observed ( $p = 0.008$ ,  $\alpha = 0.05$ ). As a direct veneer, the universal composite did not meet the acceptability threshold for any  $\Delta E_{00}$  measurements; however, the universal composite was better at matching the incisal third when compared to the other thirds. More in vivo studies are needed.

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## LIST OF ABBREVIATIONS

$\Delta E_{00}$	Delta E 2000
$\Delta E_c$	$\Delta E_{00}$ Between Cervical Tooth and Restoration Shades
$\Delta E_i$	$\Delta E_{00}$ Between Incisal Tooth and Restoration Shades
$\Delta E_m$	$\Delta E_{00}$ Between Tooth Beneath Restoration and Restoration Shades
$\Delta E_n$	$\Delta E_{00}$ Between the Cervical Tooth and Incisal Tooth Shades
3D MAC	3D Medical Application Center
$a^*$	Hue and chroma in Color Space, on a red-green axis
AACD	American Academy of Cosmetic Dentistry
$b^*$	Hue and chroma in Color Space, on a yellow-blue axis
CIE	International Commission of Illumination
DoD	Department of Defense
f	Lens aperture setting
IRB	Institutional Review Board
ISO	International Organization for Standardization (camera's sensitivity to light)
jpg	Joint Photographic Experts Group
$L^*$	Value in Color Space
LED	Light-emitting Diode
mm	Millimeters
RI	Refractive Index
SD	Secure Digital
SLR	Single-lens Reflex (camera)

VC

Vita Classical

WRNMMC

Walter Reed National Military Medical Center

# CHAPTER 1: Introduction

## BACKGROUND

Direct dental bonding is a common and popular procedure<sup>1,2</sup>, but achieving esthetically desirable shade matching with natural tooth structure continues to be challenging. Visual dental shade matching with the most used shade guide, VITA classical A1-D4 (VC), is subjective and has been shown to be an unpredictable process with varying results.<sup>3</sup> Individual color perception between providers differs immensely<sup>4</sup> and can change for the same provider from one clinical session to the next.<sup>5</sup> Furthermore, each individual tooth can display complex color transitions from cervical to incisal<sup>6,7,8</sup> and tooth shades are influenced by the color temperature of varying light sources,<sup>9,10</sup> making shade-matching more difficult.

To mitigate these challenges, providers have shade-matched near windows, under more than one light source, or with the use of corrective lighting devices.<sup>9,10,11</sup> Objective shade-matching technologies, such as spectrophotometers, colorimeters, and imaging software, are also available and provide shade recommendations based on known color space values of VC shades.<sup>7,8</sup> Reviews of the literature found that the use of these instruments has improved accuracy and matching when used in combination with a shade guide.<sup>7,8</sup>

The International Commission of Illumination (CIE)  $L^*a^*b^*$  is an example of a commonly used color space model in dentistry where  $L^*$  represents value, while  $a^*$  and  $b^*$  correspond with chroma and hue on a red/green and blue/yellow scale, respectively.<sup>7,8</sup> Delta E 2000 ( $\Delta E_{00}$ ) characterizes the difference of a color coordinate versus another and

indicates how closely matched those colors are using the given L\*a\*b\* values.<sup>7,8,12</sup> The lower the  $\Delta E_{00}$ , the better the match. There are noted differences in the dental literature as to what value of  $\Delta E$  is deemed “visually imperceptible” and “visually acceptable”. Paravina, et al., determined the values of  $\Delta E_{00} \leq 0.8$  and  $\Delta E_{00} \leq 1.8$  for perceptibility and acceptability thresholds, respectively, with acceptability having a higher clinical relevance.<sup>13</sup>

The formulation of resin composites has changed to render more esthetic results.<sup>14</sup> Multi-shade composite systems come in 16 shades and different opacities to match each of the 16 shades represented by the VC guide, while group-shade composite systems tout that they cover all 16 VC shades with fewer products.<sup>15</sup> More recently, the marketing of a single-shade composite – a composite system capable of matching all VC shades from A1-D4 utilizing a single product – has become a product of interest.

These companies advertise that they are more economical by reducing the guesswork and time associated with shade-matching and eliminating the need to purchase and stock seldom used shades.<sup>16,17</sup> Generally, they claim that these products can achieve the desired shades by the concept of structural color – rather than added pigments or dyes – that allow light to pass through the particles, contact the surrounding tooth structure, reflecting the natural tooth’s shade.<sup>16,17,18,19</sup>

One manufacturer claims that their universal composite can be used for all Greene Vardiman (G. V.) Black classifications, and it can be used as direct veneer.<sup>16</sup> There is literature that supports this universal composite’s purported chameleon affect. These studies have demonstrated that it can modify its shade following bleaching,<sup>20, 21,22</sup> when stains are applied,<sup>20,23,24</sup> and when measured from bench-top fabricated discs of the resin

to that of the resin placed in Class V lesions of extracted teeth.<sup>25</sup> Some evaluations and analyses showed that it had greater color and translucency adjustment potential when compared to other test composites, further supporting its shade change capabilities.<sup>26,27,28</sup>

Other literature found this structural color resin to be superior in shade-matching when compared to existing composites on the market. It exhibited the highest match potential when placed in denture teeth representing each of the 16 VC shades and compared them against four frequently used multi-shade resin composite systems<sup>29</sup>. It displayed “acceptable matching” at different depths and shades tested, performing better than the other resins tested.<sup>18</sup> Similarly, this single-shade composite was able to better match teeth of varying shades when tested against other nano-filled resins, nano-hybrid resins, or a micro-hybrid resin.<sup>30,31,32,33,34</sup>

There are also studies that contradict these findings and the product’s claims. Some studies determined that the multi-shade composites were better at color-matching when compared to the universal-shade composite.<sup>15,35,36</sup> One study found that a multi-shade composite matched better than the new universal composite when discussing darker shades like C2 and D3<sup>15</sup> while another found that the new product was worse at matching shades of high value.<sup>36</sup> Further, the only published in vivo study found an unacceptable match via spectrophotometer and visual assessment of 45 restorations on 21 subjects.<sup>37</sup>

The few existing studies investigating this universal composite have exhibited variable results and, to date, there have been no in vivo studies evaluating this product as a direct veneer. The purpose of this study is to evaluate the shade-matching and blending ability of the structural color resin, measured as  $\Delta E_{00} \leq 1.8$ , as a direct veneer restoration

in vivo, utilizing CIE L\*a\*b\* values obtained directly and indirectly. The first aim of this study was to clinically determine whether the universal composite has an acceptable match to the natural tooth structure beneath it. The second aim was to determine whether the universal composite has an acceptable match to the cervical and incisal portions of the natural tooth structure adjacent to it via digital imaging, and whether there is a difference in shade matching comparing incisal versus cervical.

## **CHAPTER 2: Materials and methods**

### **PARTICIPANT SELECTION**

This research protocol received approval from the Walter Reed National Military Medical Center (WRNMMC) Institutional Review Board (IRB), protocol # WRNMMC-2021-0360. Study participants were eligible Department of Defense (DoD) beneficiaries at WRNMMC. Inclusion criteria included subjects 18 years of age and older with an unrestored, non-carious permanent maxillary central incisor. Restoration history on permanent maxillary central incisors were obtained via screening of dental charts as well as verbal and clinical screening. Subjects who met the inclusion criteria were consented prior to participating in the study.

### **JIGS**

To ensure consistency of composite placement, biocompatible and transparent resin jigs (Dental LT Clear, Formlabs Inc., Somerville, MA) were fabricated by WRNMMC 3D Medical Application Center (3D MAC) utilizing a stereolithography 3D printing device (Form 3B, Formlabs Inc., Somerville, MA). The jigs (Fig. 1) were made with a 6.25mm-diameter round opening on the slightly convex cameo surface centered over a 7.25mm-diameter round opening on the slightly concave intaglio surface. The distance between the centers of these two openings was 1.0mm (+/- 0.01mm) thick, creating a slope between the openings. This allowed for direct contact of the tooth from the cameo surface and allowed for a thinner amount of resin to meet the tooth at the margins of the intaglio opening. The jig was also fabricated with a bite trough for seating of the incisal edge of the maxillary central incisor and its opposing dentition, allowing the

incisal edge to be consistently 2.0mm from the margin of the 7.25mm-diameter opening. A semicircular-shaped curing light tip rest was placed on the cameo surface, avoiding overlap of either opening. Finally, the jig was fabricated with mesial and distal finger rest tabs to better adapt the intaglio surface of the jig to the facial surface of the tooth, as needed.

#### **SHADE AND IMAGE CAPTURE**

A VITA Easyshade V (Vita Zahnfabrik, Bad Sackingen, Germany) spectrophotometer was calibrated and charged according to the manufacturer's instruction and recalibrated between each measurement and each subject. All values were obtained using the "base shade determination" operating mode and manually recorded in an Excel spreadsheet (Microsoft Corp., Redmond, WA).

All images were taken using a digital camera (Nikon D5600 SLR, Nikon, Tokyo, Japan) equipped with an 85-mm lens (AF-S DX Micro Nikkor 85-mm f/3.5G ED VR, Nikon, Tokyo, Japan) and a ring flash (Nissin MF18 Marco Ring Flash, Nissin, Kyoto, Japan) and stored on a secure digital (SD) card (SanDisk, Milpitas, CA). Photographs were taken utilizing standardized parameters similar to that described by de Abreu, et al.: Exposure 1/125 seconds, f (25), ISO (200), flash in manual configuration at 1/8 of its capacity, distance (~15 cm), focusing (1:1) in raw image format.<sup>35</sup>

The same, windowless, closed-door operatory was used to control the lighting conditions and the same clinical investigator conducted both the clinical and photographic aspects of the study.

## CLINICAL RESEARCH PROCEDURES AND DATA COLLECTION

A transparent Optragate (Ivoclar, Schaan, Germany) was placed for lip retraction. The left maxillary central incisor was cleaned using a prophylaxis cup and slow-speed handpiece without pumice, then air dried. The clinical investigator visually selected a shade tab using the VC shade guide (Vita Zahnfabrik, Bad Sackingen, Germany) that best matched the tooth of interest and a reference photo with the shade tab was taken, as described above. The disinfected jig was placed on the left maxillary central incisor and the subject was asked to hold the jig by placing their incisors into the bite troughs. The clinical investigator visually confirmed that the facial surface of the maxillary central incisor was as far anterior in the trough as possible (Fig. 2). The finger rest tabs were gently held down by the clinical investigator to ensure proper adaptation of the jig against the facial surface of the tooth. The  $L^*a^*b^*$  value and suggested VC shade(s) of the natural tooth structure were obtained through the jig opening using the spectrophotometer and recorded as the pre-restoration value.

With the jig still properly adapted to the tooth, Omnicroma® PLT (Tokuyama Dental, Tokyo, Japan) was then expressed into the jig opening, onto the un-etched and un-bonded tooth using a dental composite gun until filled (determined by visual examination and slight backpressure). A piece of 1-inch x 3/8-inch x .002-inch Mylar matrix strip (Henry Schein, Melville, NY) was placed over the composite and the composite flattened with a disposable periodontal probe (A. Titan Instruments, Orchard Park, NJ) for a smoother surface. The Mylar matrix strip was then lifted off the composite and excess composite was gently removed so that it was flush with the cameo surface of the jig, utilizing the same disposable periodontal probe. The Epilar Deepcure S10 LED Curing Light (3M ESPE, Saint Paul, MN) tip was placed on the jig rest and

cured for 10 seconds, per the manufacturer's recommendation, based on the intensity of the curing light used in this study.<sup>38</sup> With the jig still in place, the L\*a\*b\* value and suggested VC shade(s) of the restoration surface were recorded with the spectrophotometer through the jig opening.

The jig was removed, and a post-restoration analysis photograph was taken. The clinical investigator then visually picked a shade tab that best matched the composite and a second reference photo with the shade tab was taken. The cured composite was removed from the tooth surface with a disposable explorer (A. Titan Instruments, Orchard Park, NJ), the lip retractor and jig disposed, and the subject dismissed.

#### **COLOR AND STATISTICAL ANALYSIS**

Raw images on the SD card were converted to a Joint Photograph Expert Group (jpg) file through Batch Picture Resizer<sup>39</sup> (SoftOrbits, Version 7.0) for viewing. Digital Colorimeter<sup>40</sup> (Lindholm, Version 1.5.0) was used to indirectly obtain L\*a\*b\* values from the analysis photos (those not containing a shade tab), utilizing setting Zoom x3, and recorded on the same Excel sheet mentioned above. A total of four L\*a\*b\* values were collected from each analysis photo: two were from the restoration at its most incisal and most cervical margins while the other two were from the natural tooth, immediately adjacent to the restoration margins, in those respective locations (Fig. 3).

For each subject, a total of four  $\Delta E_{00}$  values were obtained (Fig. 4) via an established Excel  $\Delta E_{00}$  calculator<sup>41</sup> as used in other dental shade comparison research.<sup>15,24,33,35</sup> The first  $\Delta E_{00}$  value,  $\Delta E_m$ , assessed the restoration's ability to match the tooth shade beneath it, utilizing the clinical L\*a\*b\* value differences between the natural tooth structure with the jig in place and that of the restoration with the jig in place. The

$\Delta E_i$  and  $\Delta E_c$  assessed the restoration's ability to blend with the incisal and cervical tooth shade surrounding it by utilizing the  $L^*a^*b^*$  values obtained from the analysis photograph, respectively. The remaining  $\Delta E_{00}$  value,  $\Delta E_n$ , assessed the difference in natural tooth shades between the incisal third and cervical third, utilizing the  $L^*a^*b^*$  values obtained from the analysis photograph. These values were also recorded on the Excel spreadsheet.

The means for all four  $\Delta E_{00}$  values were calculated. An independent  $t$ -test ( $\alpha = 0.05$ ) was used to determine if there is a significant difference between the means of  $\Delta E_i$  and  $\Delta E_c$ .

Images that included any shade tabs were utilized as subjective references as to what was considered visually acceptable by the clinical investigator.  $\Delta E_n$  was also used as a reference to verify the shade differences between the cervical and incisal thirds of natural teeth. Neither of these items were part of the research aims.

## CHAPTER 3: Results

Ten subjects were screened and enrolled in the study ( $n = 10$ ). The means for the  $\Delta E_{00}$  values were calculated (Table 1). The mean (standard deviation) was 6.16 (2.38) for  $\Delta E_m$ , 3.90 (2.47) for  $\Delta E_i$ , 6.84 (1.80) for  $\Delta E_c$ , and 9.36 (2.55) for  $\Delta E_n$ . In addition, an independent  $t$ -test ( $\alpha = 0.05$ ) was performed to compare  $\Delta E_i$  and  $\Delta E_c$  and showed a statistically significant difference ( $p = 0.008$ ).

The spectrophotometer provided suggested shades for the natural middle third and the restoration for each subject (Table 2). Six of the subjects were recommended an A shade for the natural tooth structure, three were recommended a B shade, and one was recommended a D shade. No subjects presented with a C shade. The spectrophotometer consistently suggested A1 as the closest VC shade for each restoration. The best match shade suggested by the spectrophotometer had changed in half of the subjects when comparing natural tooth to the restoration (ex: suggested B2 for natural tooth, but A1 for the restoration).

## CHAPTER 4: Discussion

Anterior direct bonding is a popular procedure as patients desire more esthetic and economic restorative options. Natural teeth are polychromatic and obtaining an acceptable shade match is a critical aspect of dentistry. Thus, it was important to study the ability of a structural color resin composite to match natural teeth, intraorally. In this study, the mean difference between shades of the natural incisal third when compared to the natural cervical third ( $\Delta E_n$ ) was 9.36 (2.55). This value is greater than the  $\Delta E$  of 7.55 reported in the literature after examination and photographic analysis of 100 in vivo left central incisors.<sup>42</sup> Though the  $\Delta E$  formulas used between the two studies differed, our findings confirm that there is a large shade transition between the incisal and cervical thirds of a tooth.

The study subjects lacked variability in the shades presented. Half of the subjects ( $n = 5$ ) in this study presented with unrestored left central incisors in VC shade A1, though the most reported shade is A3<sup>43</sup>. The higher shade value seen in the subject population when compared to the literature may be attributed to the subjects being recruited from a military hospital where most of the patient population is generally younger and have regular access to routine dental care. The only subject who presented with a D shade also had the greatest  $\Delta E_m$  (11.48) among the subjects tested. This is consistent with one study's finding that the structural color resin was more successful at matching A and B shades when compared to C and D shades.<sup>15</sup> It, however, contradicts an in vitro study in which the single-shade composite displayed the best match with shade C3 while displaying the worst match with shade B1.<sup>36</sup>

The present study also demonstrated that the single-shade composite did not provide an acceptable match ( $\Delta E_{00} \leq 1.8$ ) as a direct veneer, in vivo. The only other published in vivo study on this resin had similar findings when it examined the structural resin's ability to match the tooth structure in anterior Class III and Class V lesions by digital and visual analysis and found significant differences and unacceptable matching.<sup>37</sup> An unexpected finding in the current study was that all the restorations in this study were recommended an A1 shade by the spectrophotometer, with respect to the middle third. This finding could be attributed, in part, to the restoration reflecting the shade of the jig that surrounded it. The jig, however, was not present in the photographic analysis of the cervical or incisal thirds, indicating that a mismatch in those regions was, in fact, present.

Unlike the methodology used in other studies, the restorations in this study were not polished. Lee, et al., demonstrated that restorations went from an unacceptable  $\Delta E$  value to an acceptable one, following polishing, with significant changes in the  $L^*$  parameters.<sup>44</sup> The lack of polishing in this study may have diminished the light reflectance of the restorative material, affecting the  $L^*$  values. Whether this would have made the resin of interest in this study deemed an acceptable match can be debated as Nagi & Moharam's study indicated that the universal-shade composite had statistically significant higher  $L^*$  values after polishing, causing the resin to be lighter than the natural tooth and, thus, rendering it an unacceptable match.<sup>37</sup>

This study also determined that the single-shade composite was better at matching the incisal third when compared to the cervical third ( $p = 0.008$ ). The incisal third is generally more translucent than the cervical third. According to the structural resin manufacturer, the product is formulated to optimize translucency by ensuring that the

refractive index (RI) of its filler and the RI of the matrix are similar in value.<sup>45</sup> Increases in RI differences can lead to greater  $\Delta E$  values and increased opacity<sup>46</sup> and is also correlated to the filler utilized as well as the percentage by weight of the monomer.<sup>47</sup> Thus, it is not surprising to see that the resin was superior at matching the incisal third. This product may potentially be used in restorations where translucency is needed to mimic a patient's natural appearance. Scenarios include use as a direct facial veneer to correct a minor malalignment involving the incisal third or to correct a small enamel defect where some translucency may be desired, given that the patient is already satisfied with their existing shade. Through this study, it appears that this product would be useful for Class IV lesions; however, the manufacturer recommends the use of its "blocker" product as lingual shelf first, then layer with the product tested in this study.<sup>16</sup> The findings of the present study also indicate that it should not be used to mask undesired shades, discolorations, or white spot lesions because of its translucency potential. Rather, the "blocker" product has been shown to be effective at this and may render the desired result.<sup>48</sup>

## CHAPTER 5: Conclusions

No study has investigated the structural color composite's ability to match and blend, *in vivo*, as a direct veneer. Utilizing objective instrumental analyses, this single-shade composite was not able to demonstrate an acceptable match at any region of the tooth examined (incisal, middle, or cervical third). However, it did display a significantly closer match to the incisal third when compared to the cervical third, statistically. As such, this product may provide improved esthetics when restoring natural tooth structure with higher translucency and where maintaining the existing shade is desired. Additional studies are needed in more diverse populations to further characterize which conditions this single-shade composite may or may not be more advantageous in comparison to multi-shade composite systems. Research to examine how this material performs with respect to shade matching and blending with the addition of its "blocker" product in Class IV lesions and in masking scenarios is also needed to objectively assess the manufacturer's claims.

**Table 1.** Means for  $\Delta E_{00}$  Values.

$\Delta E_{00}$	Mean (Standard Deviation)
$\Delta E_m$	6.16 (2.38)
$\Delta E_i$	3.90 (2.47)
$\Delta E_c$	6.84 (1.80)
$\Delta E_n$	9.36 (2.55)

$\Delta E_m$ : Difference between the natural tooth and restoration, at the middle third.

$\Delta E_i$ : Difference between the natural tooth and restoration, at the incisal third.

$\Delta E_c$ : Difference between the natural tooth and restoration, at the cervical third.

$\Delta E_n$ : Difference between the natural tooth, at the incisal and cervical third.

**Table 2.** Spectrophotometer Shade Recommendations and  $\Delta E_m$ .

Subject	Natural Tooth	Restoration	$\Delta E_m$
1	A1 <sup>B2, A2</sup>	A1	5.38
2	A1 <sup>B2, A2</sup>	A1	5.54
3	D4 <sup>C4, A4</sup>	A1 <sup>C1, D2</sup>	11.48
4	A1	A1 <sup>B1, B2</sup>	7.51
5	A1 <sup>B2, A2</sup>	A1	5.39
6	B2	A1 <sup>C1</sup>	5.13
7	A1 <sup>B2, B1</sup>	A1	2.99
8	B1	A1	5.91
9	B1 <sup>A1</sup>	A1	4.12
10	A2	A1 <sup>C1</sup>	8.14

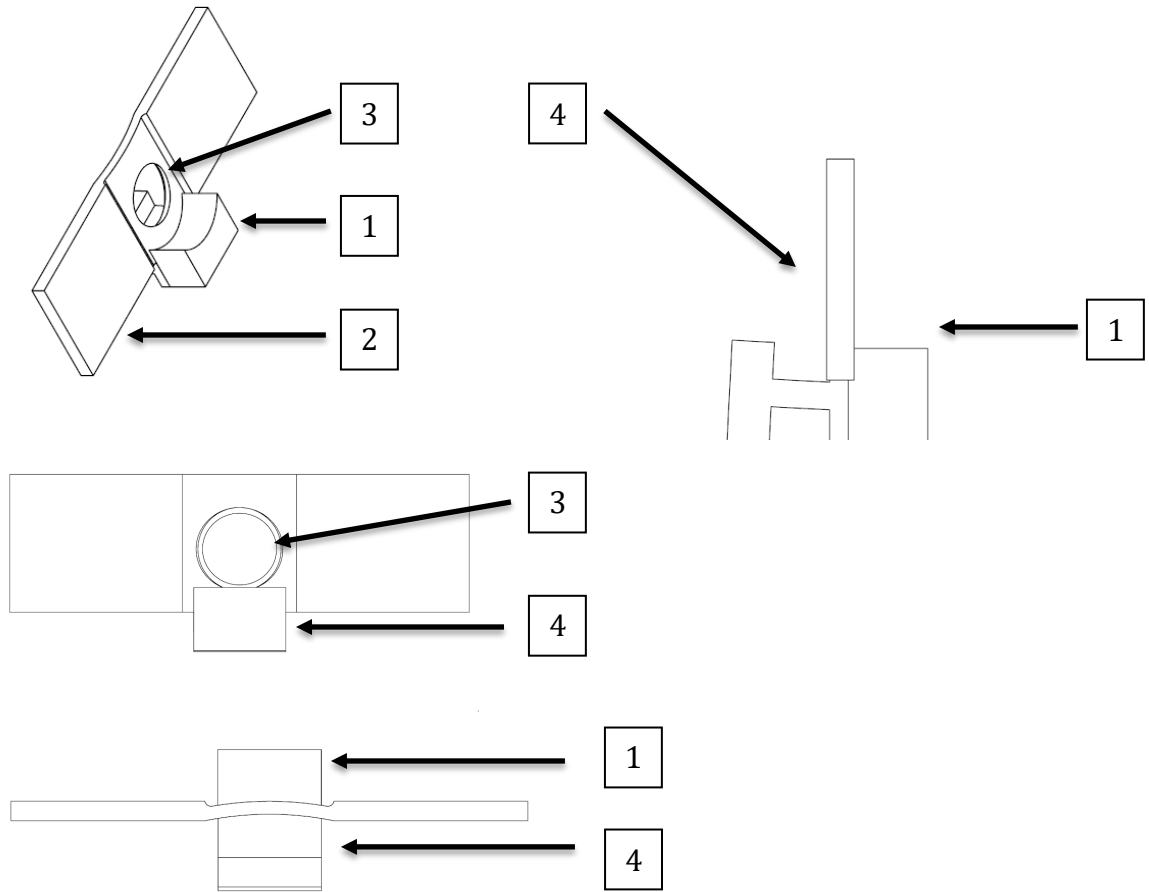
Green: No variation or slight variation from the shade recommended.

Yellow: Acceptable difference from the shade recommended.

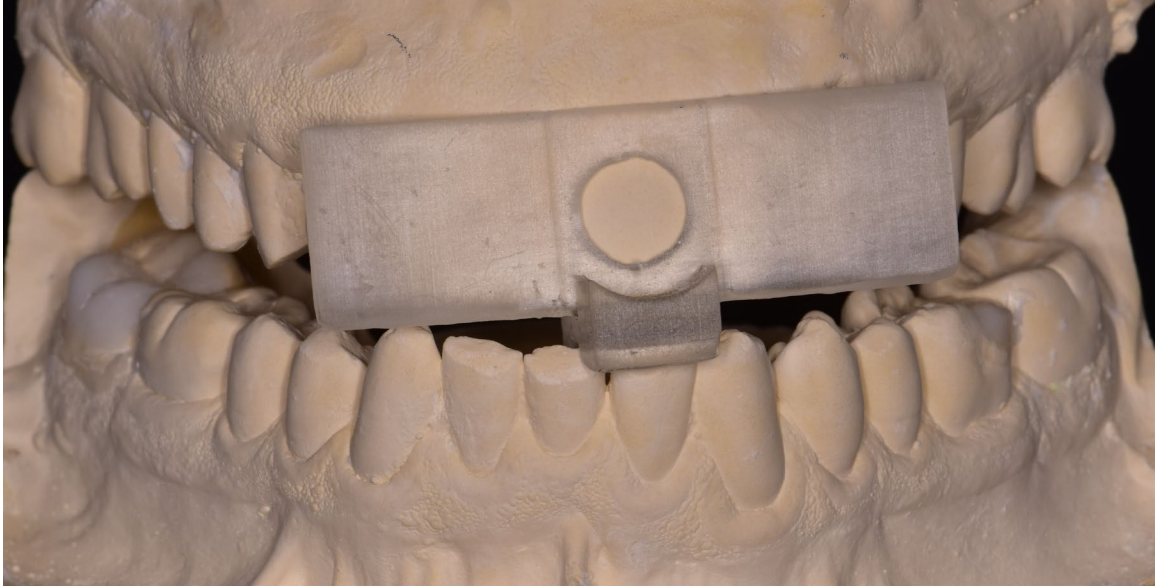
Red: Clearly noticeable difference from the shade recommended.

Superscripts: Other shades that may be useful in obtaining a good match.

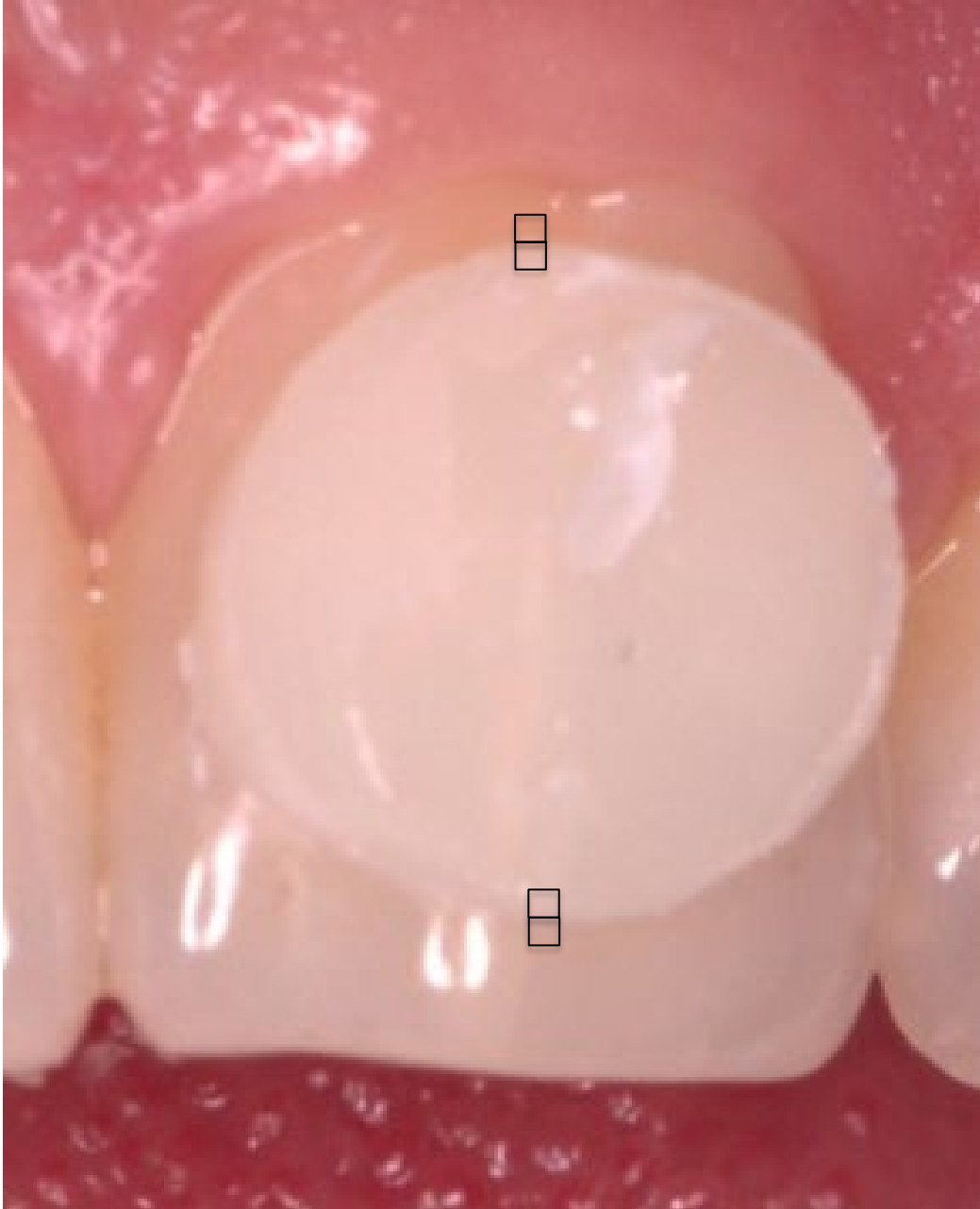
$\Delta E_m$  values were rounded to the nearest hundredth decimal place.



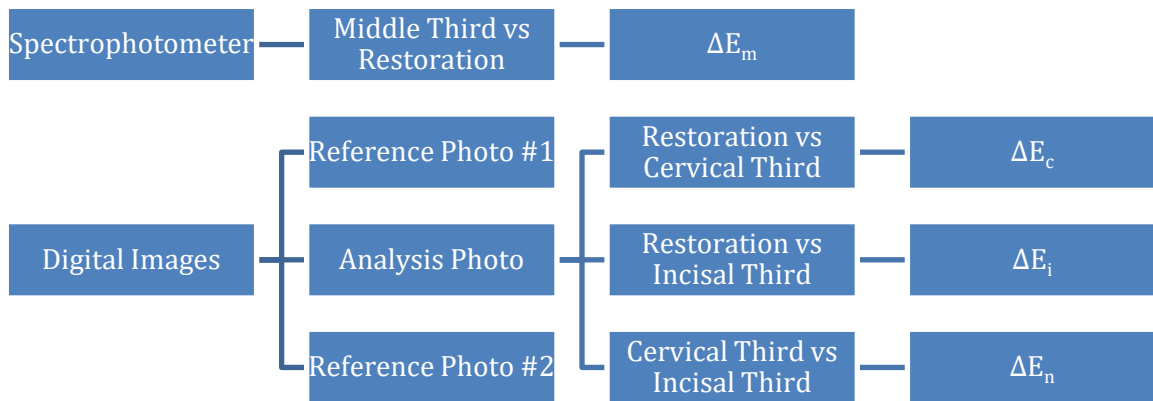
**Figure 1. Jig.** Cameo view, oblique (upper left). Lateral view (upper right). Intaglio view (middle). Superior view (bottom). 1 – Curing light tip rest, 2 – Finger rest, 3 – Opening for composite rein, 4 – Bite trough.



**Figure 2. Jig Placement.** Jig was held in place utilizing the bite troughs (top). Facial surface of the maxillary central incisor, as far anterior in the trough as possible (bottom). Note: Casts utilized for demonstration only; no casts were used as part of this shade-matching study.



**Figure 3. Obtaining CIE L\*a\*b\* Values from Analysis Photo.** Measurements were taken at the restoration's most incisal and most cervical margins from the natural tooth, immediately adjacent to the measured restoration margins. Measurement areas not drawn to scale.



**Figure 4.  $\Delta E_{00}$  Analysis Flowchart.**  $\Delta E_m$  was determined by measurements obtained from the spectrophotometer.  $\Delta E_c$ ,  $\Delta E_i$ , and  $\Delta E_n$  were determined by computer software measurements obtained from the analysis photo (no shade tab present). The reference photos (contained a shade tab) were not used to determine any  $\Delta E_{00}$  value.

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