2017

Effect of Ceramic Thickness on the Final Color of Veneer Restorations

Zainab M. Alsadah
Nova Southeastern University

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A Thesis Presented

By

Zainab M. Alsadah, D.D.S

Submitted to the College of Dental Medicine at Nova Southeastern University in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

June 2017

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Approved as to style and content by:

APPROVED BY: ______________________________

Luana Oliveira-Haas, DDS, MSc, PhD. (Committee Chair) Date

APPROVED BY: ______________________________

Amir Farhangpour, DDS (Committee member) Date

APPROVED BY: ______________________________

Evren Kilinc, DDS, PhD (Committee member) Date

APPROVED BY: ______________________________

Linda Niessen, D.M.D, M.P.H. (Dean) Date

Health Professions Division
Department of Cariology and Restorative Dentistry
College of Dental Medicine

STUDENT NAME: Zainab Majad Alsadah, D.D.S.

STUDENT E-MAIL ADDRESS: za64@nova.edu

STUDENT TELEPHONE NUMBER: (412)-482-4358

COURSE DESCRIPTION: Master of Science in Dentistry with specialization in Operative Dentistry

TITLE OF SUBMISSION: Effect of Ceramic Thickness on the Final Color of Veneer Restorations

DATE SUBMITED: June 2017

I certify that I am the sole author of this thesis, and that any assistance I received in its preparation has been fully acknowledged and disclosed in the thesis. I have cited any sources from which I used ideas, data, or words, and labeled as quotations any directly quoted phrases or passages, as well as providing proper documentation and citations. This thesis was prepared by me, specifically for the M.S. degree and for this assignment.

STUDENT SIGNATURE: ______________________________

Zainab M Alsadah, D.D.S. Date: 06/14/2017

DEDICATION

This thesis work is dedicated to the soul of my parents: Majed and Aisha, who had always loved me unconditionally and whose noble model had taught me to work hard for the things that I aspire to achieve.

This work is also dedicated to my beloved brothers and sisters who have been a constant source of support and encouragement during the challenges of graduate school and life. I am truly thankful for having all of you in my life.

To my beloved daughter: Reema, whom I can't force myself to stop loving.

To all my family, the symbol of love and giving. To my professors and friends who encourage and support me all the time and to all the people in my life who touched my heart, I dedicate this research.

ACKNOWLEDGEMENTS

I would like to acknowledge the following individuals:

Dr. Luana Oliveira-Haas, for chairing my thesis committee. I am so grateful and honored for all your support, help and guidance throughout this process. I have learned so much from you during my postgraduate study.

Dr. Amir Farhangpour and Dr. Evren Kilinc, for serving on my committee. Thank you for your guidance and assistance during my postgraduate study.

Dr. Richard Singer and Dr. Jeffrey Thompson, I greatly appreciate your guidance and help with my research study.

Dr. Patrick Hardigan, for the kind help and assistance in the statistical analysis part of my research study.

Mr. James Rothrock, thank you for your great cooperation, help and all your assistance in the Bioscience Research Center Lab at Nova Southeastern University.

Dr. Zohaib Munaf, thank you for your help in my research study.

Ms. Maddeline Manus and Mrs. Patrice Stack, thank you for all your support and assistance with the administrative and paperwork parts of my research study.

ABSTRACT

EFFECT OF CERAMIC THICKNESS ON THE FINAL COLOR OF VENEER RESTORATIONS

DEGREE DATE: JUNE 2017

ZAINAB MAJAD ALSADAH, D.D.S.

COLLEGE OF DENTAL MEDICINE, NOVA SOUTHEASTERN UNIVERSITY

Thesis Directed by: Luana Oliveira-Haas, DDS, MSc, PhD, Committee Chair

Amir Farhangpour, DDS, Committee Member

Evren Kilinc, DDS, PhD, Committee Member

Background: The integration of ceramic veneer thickness and substrate color are very challenging factors that dentists and lab technicians should control to achieve a good color match. The reproduction of a natural and homogenous color can be laborious when laminate veneers of 0.4 to 1.2 mm thick are cemented over a dark underlying substrate. **Objective:** The purpose of this in vitro study was to investigate the association of different ceramic veneer thicknesses cemented on different tooth substrate colors and its influence on final color match of ceramic veneers. **Material and methods:** Ninety slices IPS e-max CAD (Ivoclar Vivadent, Amherst, NY, USA) ceramic veneers shade A1 were fabricated with three different thicknesses (0.4, 0.7 and 1.0mm). The thickness of 0.4mm corresponds to the minimum thickness that the CAD/CAM milling unit can fabricate for minimally invasive veneers. Additionally, ninety slices were fabricated from light-cured composite resin material shades (A1, A3 and C4) representing the tooth substrate color (stump shade), Filtek Supreme (3M ESPE, St Paul, MN, USA). The ceramic slice was bonded to the composite resin material using light cured neutral shade resin cement (Variolink Esthetic, Ivoclar Vivadent, Amherst, NY, USA). The specimen combinations were divided into 9 groups (n=10/group). Color parameters CIE lightness (L*), chroma (A*), and hue (B*) values were measured using a digital spectrophotometer (Gretag Macbeth Color-Eye® 7000A). Shade A1 was used as control. A 2-way analysis of variance (ANOVA) was used to compare the means and standard deviations between the different color combinations (α=0.05), followed by Tukey's HSD post hoc test for significant interactions. **Results**: A two-way ANOVA was conducted to examine the effect of stump shade (A1, A3, C4), ceramic thickness (0.4mm, 0.7mm, 1.0mm), and the interaction effect of stump shade by ceramic thickness on Delta E value of 3.3. We tested the model for equal variances using Bartlett's test and found them to be equal. There was a statistically significant effect of stump shade $F(2, 81) = 513.80$, $p < 0.001$, Eta-Squared = 79.1%; ceramic thickness $F(2, 81) = 60.35$, $p < 0.001$, Eta-Squared = 9.2%; and the interaction effect of stump shade by ceramic thickness, $F(4, 81) = 17.28$, $p < 0.001$, Eta-Squared = 5.8% on Delta E value of 3.3. **Conclusion**: It can be concluded that, the final color of ceramic veneer is highly affected by the different stump shades and thickness of the ceramic veneer. Also, color mismatch or reflection of the stump shade may occur in thin veneers obtained from CAD/CAM blocks after cementation. Moreover, the ΔE values for thin veneers were higher than the values obtained from thick specimens; referring to the preference of thicker ceramic with lower translucency in terms of clinical relevance.

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CHAPTER 1

Introduction

1.1 Color Description and Measurements:

1.1.1 Overview:

Because of the complex optical characteristics of color on natural dentition, it is challenging to achieve a clinically acceptable shade match between the natural teeth and artificial tooth restorations.[1,2] Moreover, color studies in dentistry have increased dramatically over the past several decades.[1] The Commission Internationale de l'Eclairage (CIE) or the International Commission on Illumination describes the color as "An attribute of visual perception consisting of any combination of chromatic and achromatic components".[3]

In 1986, Seghi et al described the color for natural teeth as a result from combination of light reflected from the enamel surface and the light scattered and reflected by the enamel and dentin.[4] The human eye is very skillful at detecting small color differences. Loss of shade match or change in color with the surrounding natural teeth is one of the main reasons for replacement of esthetic restorations.[5,6] Thus, there are some critical factors involved in achieving a successful esthetic dental restoration. These include: the light source used for color evaluation, the individual's perception of color, the surface and structural characteristics of both the tooth and the restorative materials, and knowledge of some basic principles of color perception, together clinicians will have the ability to give clear instructions to technicians when indirect procedures are performed.[2]

Color changes can be measured visually and by using different instrumental techniques.[7] Visual color measurement is primarily subjective and can be affected with a number of factors such as: surface texture, lighting conditions, translucency, material properties and the operator's color sensation.[8] Using instrumental techniques based on optical sensors will reduces the subjective analysis, allows objective evaluation of color permits the impartial evaluation of color and decreases the personal interpretation inherent in visual color judgment.[7,8] Consequently, a spectrophotometer is mainly used to evaluate and characterize color and color differences.[7]

1.1.2 CIE Standards:

In 1976, the CIE established a color scale system called CIE *L*a*b* and* it provides a reliable standard with a uniform color scale.[3,9,10] The CIE L*a*b* scale expresses color by numerical values and calculate the difference between two color coordinates in which: L* represents the lightness or darkness, a* is a value of redness (positive a*) or greenness (negative a*) and b* is a value of yellowness (positive b*) or blueness (negative b*).[9] Consequently, as *a** and *b** values increase, the chroma of color increases.[9,11] This system is specifically preferred in dental research because it allows users to evaluate color attributes, accurately express their findings to others in numerical terms and its correlates well with how the human eye perceives color. Both industry and dentistry depend now on color difference measurements. Certainly, one single value is not adequate for color matching. Therefore, differentiation between perceptibility (the difference that can be recognized by the human eye) and acceptability (the difference that is considered tolerable) were proposed.[8] Clarke and Colleagues in 1983,[9] proposed the total difference in color between two items, and derived the concept of ΔE, which can be calculated by applying the formula:

$$\Delta E^* = [(L1^* - L2^*)^2 + (a1^* - a2^*)^2 + (b1^* - b2^*)^2]^{1/2}$$

In the $L^*a^*b^*$ color space, ΔE indicates the degree of color difference but not the direction of the color difference. Even though there is much variability between humans for color matching, it is beneficial to identify the acceptable range of color differences between shades of esthetic dental restorative materials and the teeth that need to be restored. Several studies done by Erdemir et al., 2002; Schulze, Marshall, Gansky, & Marshall, 2003 showed that a value of $\Delta E > 1$ is visually detectable, and a value of $\Delta E > 3.3$ is a critical value that represents a clinically significant visual color change, noticeable by most humans with average vision.[7, 12]

Studies suggest that detection of a color difference depends on a combination of eye characteristics and skill of the operator. According to their findings, ΔE values of less than 1 were found to be not discernable by the human eye. ΔE values greater than 1 but less than 3.3 were noticeable by some skilled operators, but were deemed clinically acceptable. ΔE values greater than 3.3 were considered to be noticeable by untrained operators and observers, and considered to be clinically not acceptable.[13,14,15]

1.1.3 Instrumental Color Measurements:

The optical determination of tooth color with traditional shade guides is a subjective technique of color communication, conditional on some factors such as the light source, the operator, and the tooth.[16] Also, there is an important connection of human perception of shade variation with the evaluation of the polished ceramic, color analysis, surface texture, and the effect of glaze on ceramic.[17] However, the determination of tooth color can be enhanced using devices such as colorimeters or spectrophotometers, which have been developed to precisely measure color and color difference.[1] Colorimeters measure tristimulus values and filter light in red, green and blue areas of the visible spectrum. Colorimeters considered to be less accurate than spectrophotometers because they are not recording spectral reflectance and filters aged with time and affect the reading accuracy.[18]

The spectrophotometer measures the color based on the CIE L*a*b* color space system, which allows measurement of color in three-dimensional space.[19] And as have been mentioned, the color difference between two objects is represented as (ΔE). Furthermore, spectrophotometers can detect small differences in color at a level that is not visible by the human eye. Also, they are one of the most accurate, useful and flexible instruments for overall color matching in dentistry.[1] It has been built to reflectance from or transmittance through a material as a function of wavelength, giving the entire spectral curve. Though, this approach is limited to the visible frequency range (usually 350–800 nm) in assessing color.[2,20]

Spectrophotometers measure the amount of light energy reflected from an object at 1–25 nm intervals along the visible spectrum.[1] Moreover, a spectrophotometer can measures the color based on the CIE *L*a*b** color space system, which allows measurement of color in three-dimensional space.[20] Another significant advantage is the ability to analyze the principal components of a series of spectra, even from a secondary source, and the ability to convert this data to various color measuring systems. These devices possess software that can be used in conjunction with images taken with a digital camera. The images can be sent to a spectrophotometer, which in some cases is combined with an imaging system. This can be particularly useful in clinical dentistry.

1.2 Indirect Tooth Restorations:

1.2.1 Overview:

It has been recognized that dental esthetics is one of the most significant factors for patient, and this might have a major impact in patient psychological parameters and self-confidence.[21] Though, anterior direct restorations offer an excellent esthetic substitute to lost tooth structure, manufactures have developed several indirect alternatives to gold and alloy restorations to replace the missing part of tooth structure either fully as with all ceramic crowns, or partially as with inlay, onlay, or laminated veneers.[22] The introduction of new materials and sophisticated treatment with dental veneers has helped dentists meet many of the esthetic challenges presented in the field of cosmetic dentistry. Moreover, advanced management in restorative treatment modalities have allowed the treating dentist to produce results that provide outstanding esthetics, and also achieve outcome that provides a natural matching color over the long term.[21] However, working in the esthetic zone and achieving the desired color is a big challenge. Though, for the past few decades, dental ceramic restorations have been widely used because of their excellent esthetics as they have natural light reflectance, no discoloration overtime, biocompatibility and improved physical properties.[23] However, ceramic restorations are fabricated indirectly, where a laboratory construction is required and then delivered for cementation to the tooth. Therefore, color matching is very challenging and requires a clear communication between dentist and lab technician, also understanding of color principles between the team to achieve the desired esthetic result.

1.2.2 Ceramic Veneer Restoration:

A veneer can be defined as "Thin bonded ceramic restoration used to restore the facial surface and part of the proximal surface of a tooth".[24] Porcelain laminated veneers (PLVs) and ceramic restorations have become one of the most popular approaches in the anterior area due to their natural appearance and esthetics. Also, the ability of ceramics to match natural dentition, and the good physical and optical properties of ceramics make them the material of choice for patients with high esthetic expectations. Charles Pincus in 1937 first introduced veneers. He used them for a temporarily esthetic enhancement of teeth shapes in movie stars.[25,26] Simonsen and Calamia, first described the feldspathic porcelain veneer retained by an acid etch technique as demonstrated by a laboratory published study.[24,25] Afterward, Horn published the first report of the clinical application of that method.[27] However, the use of ceramic veneers didn't enter much of dentistry until the early 1980s, when enamel etching and surface treatments of porcelain become available.[26,28]The success of ceramic veneers has been related to the strong bond between two materials of similar elastic modulus, porcelain and enamel.[29]

One review article by Layton & Clarke, 2013, reported that the survival rate for all ceramic crowns has been greater than 90%, irrespective of observation period and material used. Other studies have reported survival rates of 96% for veneers at 5 years and 91% at 10-13 years.[28] There is no agreement on the optimal veneer design in the literature.[23,24,26,28,30,31] However, a conservative tooth preparation helps optimize the emergence profile and provides a definite finish line. Authors agreed that the conventional porcelain veneer thicknesses should range from 0.3 to 1.0 mm.[21,23,29] Additionally, the best long-term result in regards to retention will be achieved if 50% of the preparation is kept on enamel and the entire finish lines end on enamel as well.[23] This is one of the main challenging for color match because part of the preparation will be on enamel and the rest is on a yellower dentin.

Previous study by Turgut & Bagis in 2013 have shown how the thickness of ceramic will affect the final color of veneers after cementation.[32] In 2009, Terzioglu H et al, stated that the differences in the cement shade did not significantly affect the final color of the ceramic specimens for any thickness, and color shifts were not perceivable between the different shades of cement.[33] Also, in 2013, Turgut S and Bagis B stated that the type and shade of resin cement and the thickness and shade of the ceramic influenced the resulting optical color of laminate restorations.[32]

In fact, when a tooth has internal discoloration, ceramic veneer thickness becomes an important design consideration. As mentioned above, ceramic veneers are usually fabricated with minimal thicknesses ranging from 0.3 to 1 mm. Each case is different, and variations require careful selection of the right thickness to mask the substrate color.[21] To obtain the best esthetics, minimal thickness of ceramic veneers is required to get the most optimal results.[34] The literature describes how the thickness of veneers and other factors, such as the color of the tooth under the veneer, the color and the type of cement play a major role in the result after cementation.[32,35,13] Other studies have focused on examination and analysis of the effect of varying core and veneer thickness on the final color, and showed that the color appearance of the layered ceramic is strongly influenced not only by the core thickness and veneer thickness, but also by their interaction.[36] However, the perception of color by an observer is subjective, which results in unpredictable differences in color evaluation and matching among clinicians. Other previous study by Barizon et al., 2014 have evaluated the relationship between visual criteria and instrumental colorimeter to measure color.[37]

1.2.3 Indications:

In the 1980s, veneers delivered a conservative treatment for tooth misalignment, unaesthetic shape and form, and discoloration.[24] At present, ceramic veneers are indicated to correct tooth form and position, replace old composite restorations, close diastemas, restore incisal abrasions and tooth erosion, and to mask and reduce tooth discoloration.[23] Esthetically, veneers should be translucent enough to maximize the light transmission but also opaque enough to mask any discoloration.[28]

In a clinical situation where tooth whitening (bleaching) is not indicated, or a lighter color cannot be achieved due to intrinsic discoloration, such as occurs with endodontically-treated teeth, or when there is significant teeth misalignment, ceramic veneer is a conservative and appropriate solution to attain a desired color, but the amount of tooth structure to be reduced is always a question.

1.2.4 Categories and Type of Materials:

The material of choice in the esthetic zone should allow the clinician to pursue durable, cost effective, and simple intervention with acceptable survival rates, which meet patient expectations and allow function. Dental ceramic restorations have been widely used in past decades because of their excellent esthetics and biocompatibility, in addition to conservation of tooth structure. However, since acid-etched ceramics were introduced in the 1970s, porcelain veneers have been widely used in dentistry.[37] For many years, conventional feldspathic porcelains were considered the best material of choice for veneer restorations to provide optimal esthetic results. Feldspathic porcelain is a glass ceramic based on naturally occurring feldspar, which is, composed of silica and alumina as main elements, with some of potassium oxide and sodium oxide.[37] Traditional feldspathic porcelain has typically been used only for veneers and for veneering metal-ceramic prosthetics. These ceramics are typically crafted using powder and liquid by hand.[37] Moreover feldspathic porcelain veneers help cover enamel precisely, because they require minimal tooth preparation and thickness. However, study done by Sadowsky, 2006 reported that the most common failures noted with this material were fracture, microleakage, or debonding.[38] This has led to the development of stronger materials, and a better understanding of the tooth-restoration bonding mechanism.

In the 1990s, pressed ceramics such as IPS Empress (Ivoclar Vivadent, Schaan, Liechtenstein), with 40% to 50% increase in leucite volume fraction when compared to feldspathic porcelain and Empress 2 (Ivoclar Vivadent, Schaan, Liechtenstein), based on lithium disilicate glass ceramic chemistry, became available. However, those pressed ceramics required deeper tooth preparations to compensate for their required thickness and marginal mechanical properties. This type of tooth reduction exposes more dentin than the traditional preparations.

Newer ceramic systems, which carry manufacturers' claims of translucent properties comparable with feldspathic porcelains, along with improved mechanical behavior, have been introduced in dentistry. By the beginning of the 21st century, computer-aided design/computer-aided manufacture (CAD/CAM) technology became available. This technology utilized many materials including Vita Mark porcelain (Vita Zahnfabrik, Bad Sackigen, Germany), Procera alumina (Nobel Biocare, Zurich, Switzerland), reinforced porcelain (Empress, Ivoclar Vivadent, Schaan, Liechtenstein), IPS e.max Press (Ivoclar Vivadent, Schaan, Liechtenstein) and zirconia.[28] The introduction of lithium disilicate glass ceramic (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein) allowed the fabrication of more durable posterior and anterior crowns, and thin anterior veneers.[37] One of the most important and required micromechanical properties for ceramic veneers is the ability to etch the prosthetic surface to facilitate better retention of the restoration. Moreover, it should be strong in tension and compression, and maintain its marginal seal, luster, and shade over time. Alumina and zirconia are difficult to etch, in addition to possessing poor esthetic characteristics, and consequently are not appropriate for veneers.[28]

A material's thickness has been shown to directly affect its translucency.[39] However, information regarding the translucency parameter (TP) of these new systems and the effect of different ceramic shades on translucency is insufficient. Moreover, previous study by Chaiyabuter et al., 2011 showed how the color of cement and ceramic thickness affect the final color after cementation, by using light colored substrates.[35] Very few studies by Azer et al., 2011; kilinc et al.,2011; Terzioglu et al.,2009; Turgut & Bagis, 2013 used at least one dark color with only one thickness to test the effect of colored cement on the final shade. [21, 22, 32, 33] Yet none of the previous studies by Azer et al., 2011; kilinc et al.,2011; Terzioglu et al.,2009; Turgut & Bagis, 2013 tackled the use of very minimum thickness of opaque veneers with neutral color of cement. [21, 22, 32, 33] In this study the investigators were intend to find solutions to the problem of masking a dark substrate structure under a cemented laminate veneer. Furthermore, different ceramic systems designed for veneer restorations present varying degrees of translucency. The thickness and shade of ceramic affects its translucency. Testing varying ceramic thickness on different shades of dentin helps dentists to select the proper thickness to conceal the substrate color. This study was attempt to identify the appropriate minimum thickness of a ceramic veneer that could conceal the dark shades of tooth structure without interfering with other factors such as color of cement.

1.3 Luting Agents:

1.3.1 Overview:

Luting agents or restoration cements are primarily used to fill the space between a tooth preparation and the indirect dental restorations. The cement prevents any dislodgment and helps in retaining the restorations to the tooth during function.[40] There are various types of cements with specific characteristics that suit different clinical situations. With the expanding variety of available dental materials, a broad range of indirect restoration options is possible. Because of this, cements have been developed to address strength, solubility, and esthetics concerns. Many types of dental cement are available, such as zinc phosphate, zinc oxide eugenol, zinc oxide non-eugenol, resin, glass-ionomer, resin- modified glass-ionomer, and polycarboxylate.[40] Literature reports three types of retention mechanisms for restorations retained by dental cements.[38, 40, 41] These are chemical, mechanical (friction), or micromechanical (hybridized tissue). Usually, the restoration is retained by a combination of two or three mechanisms depending on the substrate and the nature of the cement.[42] Improper selection and manipulations of specific cements can have a significant impact on a restoration's longevity. The most commonly used cements for esthetic dental procedures are resin based or glass ionomer cements.[40,43]

1.3.2 Types and Classification:

Luting cement materials are commonly categorized by their mechanism of matrix formation or setting reaction of polymerization. They can be self- or auto-polymerized, light cured, or dual-cured.[41] Chemically activated or self-cured material is initiated by mixing two pastes. The main disadvantages of those materials are trapping of air (oxygen) during mixing and short working time after mixing. Polymerization of light activated materials is initiated by blue light at a peak wavelength of 470 nm, which is absorbed by a photo-activator, such as comphorquinone.[44] Those materials offer extended working time, setting on demands, and improved color stability. However, they are limited to shallow cementations like veneers, inlays, and restorations with minimal thickness and lighter colors, which do not affect the capability of the curing light to polymerize the cement through the restoration.[42] Dual-cured resins were introduced to combine the favorable properties of both self- and light-cured resin. The main advantages of these materials are extended working time and the ability to reach a high degree of conversion and polymerization either with or without the presence of light.[45] However, resin cements showed a superior statistical result when compared to other types of cements (i.e. resin modified glass ionomer, glass ionomer, or zinc phosphate cements).[46]

1.4 Purpose of the Study:

The purpose of this in vitro study was to investigate the association of different ceramic veneer thicknesses cemented on different tooth substrate colors, and its influence on final color match of ceramic veneers.

1.5 Research questions:

1. Does ceramic thickness affect the final color of A1 ceramic veneer when placed on a substrate with a dark color (A1, A3, and C4)?
2. Is a thicker ceramic veneer able to block the dark color of tooth substrate after cementation?

In this study, the effect of ceramic thickness on the final color of a cemented veneer was evaluated. The findings of this study could help dentists and lab technicians make more appropriate decisions selecting proper thickness of a veneer when dark shades of tooth substrate are present.

1.6 Specific Aim and Hypotheses:

1.6.1 Specific Aim:

Was to determine the minimum ceramic thickness able to hide a dark tooth substrate color, with the combination not perceptible by an average person and without affecting the final shade of the veneer itself.

1.6.2 Null Hypotheses:

There is no difference on color of veneers after cementation with different ceramic veneer thickness on a dark tooth substrate.

1.7 Location of the Study:

The design, preparation and data collection of the study took place at:

Bioscience Research Center, Room 7356

Nova Southeastern University

Health Professions Division

College of Dental Medicine

3200 South University Drive

Fort Lauderdale,

Florida 33328-2018

CHAPTER 2

Materials and Methods

2.1 Experimental Design:

2.1.1 Pilot Study:

A pilot study was conducted using one sample from each study group. All techniques and equipment were adjusted and reviewed. The operator was calibrated to be familiar with all steps of clinical procedures.

2.1.2 Sample Size Calculation:

In order to determine the sample size, data from Azer S et al, was used as reference.[21] Based on sample size calculation and an additional 5% more in the sample number, it was determined that the number for each study group will be n= 10 per group.

2.1.3 Specimen Preparation:

IPS e-max ceramic CAD blocks [HT A1/I12, 10.4 x 12.5 x 15.0] (Ivoclar Vivadent, Amherst, NY, USA) shade A1 were cut in the pre-crystallized state (blue state) into slice-shaped using a diamond impregnated saw blade mounted on a low speed machine (IsoMet® 1000, Buehler ITW, Lake Bluff, IL, USA). Specimens were cut into three different thickness (0.4, 0.7 and 1.0mm), the thickness of 0.4mm corresponds to the minimum thickness that the CAD/CAM milling unit can fabricate for minimally invasive veneers. Additionally, 90 slice specimens were fabricated from light cured composite resin (Filtek Supreme, 3M

ESPE, St Paul, MN, USA), material shades (A1, A3 and C4) representing the tooth substrate color or stump shade, the size of each composite slice was 10.4 x 12.5 mm and 3mm in thickness. The ceramic slice was bonded to the composite resin material using light cured neutral shade resin cement (Variolink Veneer, Ivoclar Vivadent, Amherst, NY, USA). The specimen combinations were divided into 9 groups (*n=10*), Table 1. Detailed description of steps is given below.

2.1.3.1 Ceramic Veneer Slices Preparation

The IPS e-max CAD block were prepared by cutting out a 0.4, 0.7 and 1.0mm thickness using a diamond impregnated saw blade mounted on a low speed machine (IsoMet® 1000, Buehler ITW, Lake Bluff, IL, USA) (Figure 1, 2, and 3). All specimens were finished flat and the thickness of the slice was standardized (0.4, 0.7 and 1.0mm). Caliper was used to measure the thicknesses, and the specimens were ultrasonically cleaned in distilled water for 10 min (Figure 4). The slices were then coated on one side with a layer of neutral-shade glaze (Ivoclar Vivadent, Amherst, NY, USA) (Figure 5) and then crystallized using the manufacturer's instructions/setting. Crystallization was carried out in an Ivoclar Vivadent furnace and fired at 765 ºC (Figure 6). Completed ceramic specimens were ultrasonically cleaned in distilled water before cementation (Figure 7).

2.1.3.2 Tooth Substrate Slices Preparation

Ninety slices, 10.4 x 12.5 mm and 3mm thick were prepared in a custom-made silicon mold (Figure 8). The stump slice was simulating a tooth substrate. The samples were made by incremental packing of 2mm uncured resin composite (Filtek Supreme, 3M ESPE, St Paul, MN, USA) into the mold, which then was polymerized with a curing unit for 40 seconds through Mylar strips on the top of the specimen (Figure 9 – 14). After polymerization, each specimen was removed from the mold. Then, the specimens were dry stored for 24 hours at room temperature (Figure 15). The light intensity of the curing unit was adjusted to 600 mW/cm^2 as measured with a dental radiometer (Figure 10). All specimens were finished flat on a grinder/polisher (MetaServ® 2000, Buehler ITW, Lake Bluff, IL, USA) with wet #600 to #1200 grit silicon carbide paper (Figure 16,17, and 18) and the thickness of the specimens were standardized. Caliper was used to measure the thicknesses, and the specimens were ultrasonically cleaned in distilled water for 10 minutes.

2.1.3.3 Light-cured Adhesive Resin Cement

A light-cured neutral shade adhesive resin cement (Variolink Esthetic Cement, Neutral shade, Ivoclar Vivadent, Amherst, NY, USA) was used in the study (Figure 19). To simulate a clinical situation, manufacturer's instructions were followed.

2.1.3.4 Ceramic Veneer Slices Pre-Cementation Process:

Ceramic veneer slices were etched with 37% phosphoric acid for 15 seconds, then rinsed off and dried to clean the surface. Slices were then etched with hydrofluoric acid for 15 seconds (Figure 20), rinsed (Figure 21), and dried. Silane was applied to the inner surfaces of the veneer (Monobond Plus, Ivoclar Vivadent, Amherst, NY, USA) and left to react for 60 seconds (Figure 22). Subsequently, the surface was air-dried with oil-/moisture-free air.

2.1.3.5 Tooth Substrate Slices Pre-Cementation Process:

Total Etch (37% phosphoric acid) was applied to the prepared resin slices for 15 seconds (Figure 23). Slices were then rinsed with water for 5 seconds, and the slice surface was left slightly moist for wet bonding (Figure 24). This was done with: compressed air, a high-volume evacuation tip held directly over the prepared slice for 1–2 seconds, and a dry brush. Then primer and bonding agent was applied to the prepared slice (OptiBond™ FL, Kerr Corporation, Orange, CA, USA). (Figure 25)

2.1.3.6 Cementation Process:

The prepared thickness of the resin cement applied to each specimen was 50 microns in accordance with ISO 4049-2000 for the maximum thickness of luting materials. To achieve this thickness, the following technique was used: Mylar strip was placed on top of each slice-shaped composite specimen to provide a thickness of fifty microns (Figure 26). A small drop of the cement was placed on top of each resin slice (Figure 27). Then a prepared ceramic veneer was positioned on top of the resin cement (Figure 28). Next, the whole unit (the resin tooth substrate, the cement and ceramic veneer) was placed in the Metlab Sample Leveling Press Device (MetLab Corporation, Niagara Falls, NY, USA) (Figure 29), and a one hundred twelve and half gram weight was positioned over the whole unit for 15 seconds (Figure 30 and 31). The objective of this technique was to create a consistent cement layer. The weight was compressing the cement specimen to the thickness of the thin Mylar strip. The Mylar strip was then created space between the top and bottom layer, giving a cement thickness that was equal to the thickness of this strip, 50 microns. Then, the slice was cured for

5 seconds from each side. After that the weight was removed and excess cement was cleaned. All the margins were covered with glycerin gel (Liquid Strip) to prevent oxygen inhibition and a curing light tip was placed on each side of the specimen for 20 seconds. This procedure was holding the specimen in place and ensured that the light tip is placed at the same distance and in the same position for all specimens (Figure 32 and 33).[47]

2.2 Experimental Groups:

Study groups can be found on Table 1. Table 2 presents all materials were used in the study.

90 combined ceramic/stump specimens were divided into nine groups according to stump shade (Dentin shades: A1, A3 and C4) and thickness of ceramic (0.4, 0.7 and 1.0 mm). Each group has 10 samples (*n=10*) and all the ceramic slices were A1 in shade and composite/tooth substrates were 3mm thick. The description of each group was as follow:

Group 1: Composite dentin shade A1 bonded to 0.4 mm e-max ceramic veneers.

Group 2: Composite dentin shade A1 bonded to 0.7 mm e-max ceramic veneers.

Group 3: Composite dentin shade A1 bonded to 1.0 mm e-max ceramic veneers.

Group 4: Composite dentin shade A3 bonded to 0.4 mm e-max ceramic veneers.

Group 5: Composite dentin shade A3 bonded to 0.7 mm e-max ceramic veneers.

Group 6: Composite dentin shade A3 bonded to 1.0 mm e-max ceramic veneers.

Group 7: Composite dentin shade C4 bonded to 0.4 mm e-max ceramic veneers.

Group 8: Composite dentin shade C4 bonded to 0.7 mm e-max ceramic veneers.

Group 9: Composite dentin shade C4 bonded to 1.0 mm e-max ceramic veneers.

2.3 Spectrophotometer Analysis

The colors of specimens of all groups were measured with a spectrophotometer (Gretag Macbeth Color-Eye® 7000A, Figure 36) calibrated with a white standard (X = 93.39, Y = 95.31, Z = 112.46). The tristimulus values (X, Y, and Z) of the specimens were transformed to CIE L*a*b* values. [48]

Specimens were placed and all measurements were recorded in CIE L*a*b* values coordinate with a spectrophotometer by a single operator who had been trained and calibrated in using the spectrophotometer to eliminate inter-examiner reliability. The instrument calibration was evaluated before and after measurement of each specimen. The tip of the spectrophotometer was placed firmly into the calibration port and was held steadily in place until the instrument sounded a beep to indicate that the calibration was complete (Figure 37 and 38). The L*a*b* color findings of each specimen were measured three times recurrently; an average of the readings was calculated to give the initial color of the specimen.

2.4 Calculation of the Color Difference:

The L*, a*, b* values were used in the ΔE formula:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

to calculate the difference in color between groups, where ΔL^*, Δa^*, Δb^* represent the difference between L*, a*, b* values of two groups. To determine the effect of ceramic thickness and final color of the veneer, a ΔE of 3.3 was considered as the perceptibility threshold in this study.

2.5 External validity

In this study, the factors that affect the final color of the veneers, such as thickness of ceramic and shade of tooth substrate, were evaluated, so the findings of this study can help dentist to choose the right thickness of veneers relative to different shades of tooth substrate. This is a limited experimental study that has low validity; additional clinical studies still need to validate these findings for application with actual patients.

2.6 Instrumentation

In this study, standardization of thickness of specimen on each group was strictly followed; the same cementation thickness and color were used. Also, the color of ceramic veneers (shade A1) was used for all groups. In addition, the averages of three readings from the spectrophotometer were used. The same operator was performing all measurements.

1. ***Independent variable:*** shade of substrate and veneer thickness.
2. ***Dependent variable:*** shade of veneer restoration

2.7 Data and Statistical Analysis:

Descriptive statistics were calculated for all study variables. This was a 3 x 3 factorial design. The fixed effects were shades and thickness; the interaction effect was shades by thickness. To test all effects, we were using a 2-way ANOVA with Tukey HSD post hoc tests to determine the effect of ceramic thickness on the final color of the veneer restoration with different substrate shades. Statistical significance was found at $p < 0.05$. R 3.1.2 was used in all data analysis.

CHAPTER 3

Results

Descriptive statistics are found in Table 3. A two-way ANOVA was conducted to examine the effect of stump shade (A1, A3, C4), ceramic thickness (0.4mm, 0.7mm, 1.0mm), and the interaction effect of stump shade by ceramic thickness on Delta E. We tested the model for equal variances using Bartlett's test and found them to be equal. There was a statistically significant effect of stump shade $F(2, 81) = 513.80$, $p < 0.001$, Eta-Squared = 79.1%; ceramic thickness $F(2, 81) = 60.35$, $p < 0.001$, Eta-Squared = 9.2%; and the interaction effect of stump shade by ceramic thickness, $F(4, 81) = 17.28$, $p < 0.001$, Eta-Squared = 5.8% on Delta E. Results from the ANOVA model and Bon Ferroni's HSD test are found in Table 4 through Table 12, and Figure 37 and 38.

3.1 ΔE A1 Versus A3 Stump Shade:

Descriptive statistical analysis means and standard error of ΔE values for each group are given in the table according to veneer thickness (Table 6). The mean ΔE value for 0.4, 0.7, and 1.0 mm veneer thicknesses were 5.04, 3.3, and 2.68 respectively. The comparison between ΔE means for different thicknesses showed a significant difference with p=0.001. However, the post hoc Tukey's test showed the significant difference of ΔE means only between group A1 and A3 with 0.4 mm ceramic thickness (p=0.001, Table 7). Which means when the stump shade is different than the final desired shade, veneer thicknesses such as 0.4mm may not be adequate to mask the shade mismatch and as the ceramic thickness increased to 0.7 mm or more, the A3 stump shade has no effect in the final color of the veneer when it was compared to the same thickness of A1.

3.2 ΔE A1 Versus C4 Stump Shade:

Descriptive statistical analysis means and standard error of ΔE values for each group are given in the table according to veneer thickness (Table 7). The mean ΔE value for 0.4, 0.7, and 1.0 mm veneer thicknesses over A1 versus C4 stump shade were 12.50, 7.83, and 7.51 respectively. The comparison between ΔE means for different thicknesses showed a significant difference with p=0.001. A post hoc Tukey's test showed that ΔE means differ significantly between all the group (p=0.001, Table 8). Which means that increasing the ceramic thickness up to 1.0 mm was not enough to block the stump shade of C4 and there was a difference for the final color of the veneer when it was compared to A1.

3.3 ΔE 0.4 mm Versus 0.7 mm Ceramic Thickness:

Descriptive statistical analysis means and standard error of ΔE values for each group are given in the table according to ceramic shade (Table 9). The mean ΔE value for A1, A3, and C4 stump shades were 4.52, 2.93, and 1.42 respectively. The comparison between ΔE means for different shades showed a significant difference with p=0.001. However, the post hoc Tukey's test showed the significant difference of Δ*E* means only between group A1 with 0.4 mm and 0.7 mm veneer thickness (p=0.001, Table 10). Which means that as the ceramic thickness increased to 0.7 mm, there was a difference for the final color of the veneer when it was compared to 0.4 mm thickness for A1 group.

3.4 ΔE 0.4 mm Versus 1.0 mm Ceramic Thickness:

Descriptive statistical analysis means and standard error of ΔE values for each group are given in the table according to ceramic shade (Table 10). The mean ΔE value for A1, A3, and C4 stump shades were 5.48, 3.3, and 1.33 respectively. The comparison between ΔE means for different shades showed a significant difference with p=0.001. However, the post hoc Tukey's test showed the significant difference of Δ*E* means only between group A1 with 0.4 mm and 1.0 mm veneer thickness (p=0.001, Table 11). Which means that as the ceramic thickness increased to 1.0 mm, there were a difference for the final color of the veneer when it was compared to 0.4 mm thickness for A1 group.

3.5 ΔE 0.7 mm Versus 1.0 mm Ceramic Thickness:

Descriptive statistical analysis means and standard error of ΔE values for each group are given in the table according to ceramic shade (Table 11). The mean ΔE value for A1, A3, and C4 stump shades were 2.38, 1.79, and 1.31 respectively. The comparison between ΔE means for different shades showed no significant difference between the groups. Which means that as the ceramic thickness increased to 1.0 mm, there were no difference in the final color of the veneers when they were compared to 0.7 ceramic thickness for all the groups.

Final color changes of ceramic specimens were observed. There were significant differences in color changes within groups. The differences between group A1 and A3 stump shades for the ceramic thickness of 0.7 or more were insignificant, while significant differences were observed between A1 and C4 for all the thicknesses. Therefore, the null hypothesis was rejected.

CHAPTER 4

Discussion

In this study, the effect of stump color, and ceramic thickness on the post-cementation color of thin and ultra- thin laminate veneers milled from glass-ceramic blocks was evaluated. In the present study, the final color of ceramic veneers was affected by the stump shade and thickness of the veneer. Stump shade showed higher significant difference ($p<0.001$) than ceramic thickness among all groups.

The magnitude of ΔE units was used in this study to demonstrate the clinical effect of ceramic veneer thickness and the stump shade used on the final color of the specimens. As has been described, the color difference (ΔE) of two objects can be calculated quantitatively by comparing the difference between respective coordinate (L*a*b*) values of each object.[9] In contrast, qualitative visual assessments represent either a detectable color difference (perceptibility) or an unacceptable color difference (acceptability).[49] The scientific literature provides a wide range of different values of color change for the acceptable and perceptible thresholds for in vivo and in vitro conditions. In the present study, we use a ΔE of 3.3 as the perceptible ΔE threshold, and any values above that were considered clinically unacceptable. That value was consistence with what had been found in previous studies done by Archegas et al., 2011; Chen et al., 2015; and Dozic et al., 2010.[13-15]

Minimal tooth reduction, esthetics, and maintenance of healthy tissues are the major advantages of conservative preparation of ceramic laminate veneers. Since ceramic is a translucent material, dark tooth-color under these restorations is mainly reflected from beneath the restoration.[50] Additionally, this might be a disadvantage in situations with core buildup in a noticeable/visible shade underneath ultra-thin ceramic veneer restorations.[51] Even when adequate ceramic thicknesses are simulated, clinical shade matches are difficult to achieve, especially on a dark substructure.[52] To overcome this problem, ceramic thickness has been increased so that might mask the dark-colored teeth without affecting the final color of the restoration.[50]

Many important factors to consider for achieving proper shade match for the final color of the veneer.[53] However, the thickness of veneer restorations is controlled by the amount of tooth preparation/reduction. Other authors suggest keeping the preparation for a veneer on the enamel as possible to have a durable bond.[23, 27] Based on anatomical studies done by Ferrari, Patroni & Balleri in 1992, the thickness of enamel of maxillary anterior teeth ranges between 0.4-1.3 mm depending on the area of the tooth structure, and the enamel becomes thinner from the incisal third to the gingival third.[54] In addition, as the ceramic thickness decreases, the translucency of the ceramic increases.[55] Thus, the final color of the ceramic veneer will be affected as the light is transmitted through the restoration to the surface of the tooth, and the shade of the tooth will be reflected. In this study, we cemented our ceramic specimens to different stump shades A1, A3 and C4. The ΔE values measured in this study displayed an inverse relationship with stump shades. This study confirmed that ΔE values increase with darker stump shades, and that thickness has a significant effect on the overall color of a veneer restoration. A previous study by Vichi et al., 2000 concluded that when veneer thickness increased to 1.5 mm, substrate color differences could be detected only with color measuring devices, whereas when ceramic thickness is less than 1.0 mm, the color differences are readily detectable by the human eye.[55] Moreover, in 2003 Dozic et al., reported that 2 mm thick ceramic crowns were not affected by substrate color, but when ceramic thickness was 1.0 to 1.5 mm, visible color differences were observed.[56]

Authors have discussed the influence of core foundations underneath restorations to the final color of restored teeth. It is well known that dentin can be considered the primary source of color in teeth, and depending on the thickness and translucency of the overlying enamel the color can be modified. Heffernan et al., 2002 stated that the core material contributes to the overall color and translucency of a restoration.[57] In 1991 Crispin et al., determined that core translucency was one of the primary factors in controlling esthetics and color.[21, 58] Furthermore, Azer et al., 2011 concluded that the shade of the underlying core foundation or substrate has a significant influence on the final shade of 0.5 mm thick ceramic restorations, regardless to the ceramic shade.[21] Based on several studies done by Ozturk et al., 2008; Kilinc et al., 2011; Ilie & Hickel, 2008; and Bagis & Turgut, 2013, they found that the thicknesses of ceramic and tooth substrate color influence the resulting optical color of laminate restorations. Also, the risk of color change decreases as the ceramic thickness increases.[59] [22] [60] [61]

Previous studies by Dozic et al., 2010; Volpato et al., 2009; and Kumagai et al., 2013 describe how the color of cement and the ceramic thickness affect the final color after cementation when substrates were light in color.[13 62 63] Moreover, Kilinc et al., 2011, found that resin cements had no perceptible color change on the ceramic restoration. Also, they stated that even with significant color change of the resin cement, color changes weren't observable when it was covered by 1 mm ceramic thickness.[22] However, the present study was not testing the different types or shades of luting cement, therefore no conclusion regarding the influence of different cement shade can be outlined.

The limitations of this study include the fact that this is an in vitro study that will not replicate in vivo conditions, or replace well-designed clinical studies. Also, a spectrophotometer device was used for color evaluation. Therefore, the accuracy of readings is dependent on the accuracy of the equipment. In addition, the color differences of only one type of ceramic material (IPS e-max ceramic CAD blocks, Ivoclar Vivadent, Amherst, NY, USA) was evaluated. Another limitation on the study was the fabrication of slice shaped specimens rather than veneer shaped restorations. Further studies are necessary to investigate the effect of a wider range of ceramic thickness, ceramic types, and cement materials with different veneer shades on the final color outcome.

CHAPTER 5

Conclusion

Within the limitations of this study, the following conclusions were made:

- The final color of ceramic veneer is highly affected by the different stump shades and thickness of the ceramic veneer.
- Color mismatch or reflection of the stump shade may occur in thin veneers obtained from CAD/CAM blocks after cementation.
- The ΔE values between the thin and thick veneers of the same shade showed that thinner veneers have higher **"L, a or b value",** making them lighter, redder, yellower etc.
- Ceramic veneers with at least 0.7 mm thickness or more may mask an A3 shade substrate.
- Significant difference of ΔE means was observed between A1 and A3 shade substrate when 0.4 mm ceramic veneer thickness was used.
- The hue difference between the substrate and the veneer caused a significance difference in the Delta E values. Color differences on C4 groups were significantly higher when they were compared to A1 groups regardless of the ceramic thicknesses. Therefore, 1.0 mm veneer was not able to mask a C4 shade substrate.

Table 1. Study groups

Study Groups			
Stump Shade	**Ceramic Veneer Thickness**		
	0.4mm	**0.7mm**	**1.0mm**
A1	**G1**	**G2**	**G3**
A3	**G4**	**G5**	**G6**
C4	**G7**	**G8**	**G9**

Table 2. Commercial products used in the study

Consumable	Description
Ceramic	IPS e-max CAD (Ivoclar Vivadent, Amherst, NY, USA) Block HT shade A1
Composite A1	Composite resin (Filtek Supreme, 3M ESPE, St Paul, MN, USA) shade A1
Composite A3	Composite resin (Filtek Supreme, 3M ESPE, St Paul, MN, USA) shade A3
Composite C4	Composite resin (Filtek Supreme, 3M ESPE, St Paul, MN, USA) shade C4
Resin Cement	Light cure neutral shade resin cement (Variolink Esthetic LC, Ivoclar Vivadent, Amherst, NY)
Glaze	IPS e.max CAD Crystall Spray Glaze (Ivoclar Vivadent, Amherst, NY, USA)
Acid Etch	Ultra-Etch 35% phosphoric acid (UltraDent, South Jordan, UT, USA)
Porcelain Etch	9% Hydrofluoric acid (UltraDent, South Jordan, UT, USA)
Silane	Monobond Plus (Ivoclar Vivadent, Amherst, NY, USA)
Bonding agent	OptiBond™ FL (Kerr Corporation, Orange, CA, USA)
Waffering Blade	Waffering Blade 7X0.25X0.5 20HC (Buehler ITW, Lake Bluff, IL, USA)

Table 3. Descriptive Statistics

		Color Measurements for Each Ceramic Thickness		
Stump Shade		0.4 mm	0.7 mm	1.0 mm
	N	10	10	10
	M	64.46	60.38	59.07
A1	SD	0.72	0.85	1.18
	Min	63.49	59.18	57.27
	Max	65.63	62.30	60.76
	N	10	10	10
	M	59.78	57.42	56.81
A3	SD	1.49	1.04	1.25
	Min	57.97	55.59	55.41
	Max	63.20	58.88	58.89
	N	10	10	10
	M	52.73	52.97	52.42
C4	SD	1.02	0.79	0.86
	Min	51.36	51.76	51.01
	Max	54.83	54.75	53.63

Table 4. ANOVA table analysis for the effect of stump shade (A1, A3, C4), ceramic thickness (0.4mm, 0.7mm, 1.0mm), and the interaction effect of stump shade by ceramic thickness on color difference (Delta E)

Source	Partial SS	df	MS	F	Prob>F
Stump Shade (SS)	1128.59	2	564.30	513.88	$p < 0.001$
Ceramic Thickness (CT)	132.55	2	66.28	60.35	$p < 0.001$
SS * CT	75.91	4	18.98	17.28	$p < 0.001$
Residual	88.95	81	1.10		
Total	1426.00	89	16.02		

Table 5. Pairwise comparisons of color difference (Delta E values) between sample groups based upon ceramic thickness and stump shade

(Group) Shade: Thickness (mm)			Delta E	SE	Lower 95% CI	Upper 95% CI	P-Value
(G1) A1: 0.40	VS.	**(G4) A3: 0.40**	4.88	0.39	4.00	9.44	$p < 0.05$
(G1) A1: 0.40	VS.	**(G7) C4: 0.40**	12.47	0.18	12.07	27.48	$p < 0.05$
(G1) A1: 0.40	VS.	**(G2) A1: 0.70**	4.45	0.17	4.08	9.39	$p < 0.05$
(G1) A1: 0.40	VS.	**(G5) A3: 0.70**	7.09	0.13	6.81	15.52	$p < 0.05$
(G1) A1: 0.40	VS.	**(G8) C4: 0.70**	12.21	0.03	12.14	27.49	$p < 0.05$
(G1) A1: 0.40	VS.	**(G3) A1: 1.00**	5.40	0.18	4.99	11.47	$p < 0.05$
(G1) A1: 0.40	VS.	**(G6) A3: 1.00**	7.70	0.17	7.32	16.72	$p < 0.05$
(G1) A1: 0.40	VS.	**(G9) C4: 1.00**	12.61	0.09	12.40	28.14	$p < 0.05$
(G4) A3: 0.40	VS.	**(G7) C4: 0.40**	8.58	0.12	8.30	18.90	$p < 0.05$
(G4) A3: 0.40	VS.	**(G2) A1: 0.70**	2.82	0.20	2.37	5.56	NS*
(G4) A3: 0.40	VS.	**(G5) A3: 0.70**	2.66	0.16	2.29	5.35	NS*
(G4) A3: 0.40	VS.	**(G8) C4: 0.70**	8.34	0.27	7.73	17.75	$p < 0.05$
(G4) A3: 0.40	VS.	**(G3) A1: 1.00**	1.47	0.24	0.92	2.32	NS*
(G4) A3: 0.40	VS.	**(G6) A3: 1.00**	3.31	0.18	2.90	6.73	NS*
(G4) A3: 0.40	VS.	**(G9) C4: 1.00**	8.62	0.31	7.91	18.20	$p < 0.05$
(G7) C4: 0.40	VS.	**(G2) A1: 0.70**	8.05	0.09	7.85	17.84	$p < 0.05$
(G7) C4: 0.40	VS.	**(G5) A3: 0.70**	5.94	0.07	5.79	13.17	$p < 0.05$
(G7) C4: 0.40	VS.	**(G8) C4: 0.70**	0.27	0.17	-0.10	-0.07	NS*
(G7) C4: 0.40	VS.	**(G3) A1: 1.00**	7.39	0.20	6.95	15.91	$p < 0.05$

Table 5. Cont. Pairwise comparisons of color difference (Delta E values) between sample groups based upon ceramic thickness and stump shade

(Group) Shade: Thickness (mm)			Delta E	SE	Lower 95% CI	Upper 95% CI	P-Value
(G7) C4: 0.40	VS.	**(G6) A3: 1.00**	5.32	0.15	4.98	11.42	$p < 0.05$
(G7) C4: 0.40	VS.	**(G9) C4: 1.00**	0.54	0.23	0.03	0.28	NS*
(G2) A1: 0.70	VS.	**(G5) A3: 0.70**	3.31	0.11	3.06	7.03	NS*
(G2) A1: 0.70	VS.	**(G8) C4: 0.70**	7.78	0.17	7.40	16.91	$p < 0.05$
(G2) A1: 0.70	VS.	**(G3) A1: 1.00**	1.97	0.26	1.39	3.39	NS*
(G2) A1: 0.70	VS.	**(G6) A3: 1.00**	3.77	0.21	3.30	7.67	NS*
(G2) A1: 0.70	VS.	**(G9) C4: 1.00**	8.21	0.24	7.67	17.58	$p < 0.05$
(G5) A3: 0.70	VS.	**(G8) C4: 0.70**	5.70	0.11	5.45	12.44	$p < 0.05$
(G5) A3: 0.70	VS.	**(G3) A1: 1.00**	1.71	0.16	1.34	3.20	NS*
(G5) A3: 0.70	VS.	**(G6) A3: 1.00**	0.65	0.10	0.43	1.06	NS*
(G5) A3: 0.70	VS.	**(G9) C4: 1.00**	5.96	0.16	5.59	12.81	$p < 0.05$
(G8) C4: 0.70	VS.	**(G3) A1: 1.00**	7.14	0.17	6.75	15.45	$p < 0.05$
(G8) C4: 0.70	VS.	**(G6) A3: 1.00**	5.08	0.14	4.75	10.90	$p < 0.05$
(G8) C4: 0.70	VS.	**(G9) C4: 1.00**	0.64	0.07	0.47	1.14	NS*
(G3) A1: 1.00	VS.	**(G6) A3: 1.00**	2.31	0.07	2.15	4.93	NS*
(G3) A1: 1.00	VS.	**(G9) C4: 1.00**	7.45	0.14	7.13	16.26	$p < 0.05$
(G6) A3: 1.00	VS.	**(G9) C4: 1.00**	5.32	0.15	4.98	11.42	$p < 0.05$

* NS – not Significant ($p > 0.05$)

Table 6. Color differences (Delta E) for shades A1 vs. A3 as a function of veneer thickness

Ceramic Thickness (mm)	n	ΔE	SE	Lower 95% CI	Upper 95% CI	P-Value
0.40	10	5.04	0.31	4.32	5.75	0.001*
0.70	10	3.3	0.46	2.55	4.66	NS†
1.00	10	2.68	0.49	1.57	3.79	NS†
Total	30	3.78	0.30	3.16	4.39	NS†

* Significant ($p < 0.05$)
† NS – not Significant ($p > 0.05$)

Table 7. Color difference (Delta E) for shades A1 vs. C4 as a function of veneer thickness

Ceramic Thickness (mm)	n	ΔE	SE	Lower 95% CI	Upper 95% CI	P-Value
0.40	10	12.50	0.44	11.51	13.50	0.001*
0.70	10	7.83	0.48	6.73	8.92	0.001*
1.00	10	7.51	0.46	6.46	8.56	0.001*
Total	30	9.28	0.49	8.27	10.3	0.001*

* Significant ($p < 0.05$)

Table 8. Color difference (Delta E) for shades A3 vs. C4 as a function of veneer thickness

Ceramic Thickness (mm)	n	ΔE	SE	Lower 95% CI	Upper 95% CI	P-Value
0.40	10	8.72	0.64	7.25	10.18	0.001*
0.70	10	5.77	0.31	5.05	6.49	0.002*
1.00	10	5.46	0.50	4.31	6.61	0.002*
Total	30	6.65	0.29	5.84	7.45	0.001*

* Significant ($p < 0.05$)

Table 9. Color difference (Delta E) for thickness 0.4 mm vs. 0.7 mm as a function of stump shade

Stump Shade	n	ΔE	SE	Lower 95% CI	Upper 95% CI	P-Value
A1	10	4.52	0.25	3.93	5.11	0.001*
A3	10	2.93	0.69	1.36	4.50	NS†
C4	10	1.42	0.21	0.95	1.90	NS†
Total	30	2.96	0.34	2.26	3.66	NS†

* Significant ($p < 0.05$)
† NS – not Significant ($p > 0.05$)

Table 10. Color difference (Delta E) for thickness 0.4 mm vs. 1.0 mm as a function of stump shade

Stump Shade	n	ΔE	SE	Lower 95% CI	Upper 95% CI	P-Value
A1	10	5.48	0.36	4.66	6.29	0.001*
A3	10	3.3	0.59	2.24	4.92	NS†
C4	10	1.33	0.12	1.05	1.61	NS†
Total	30	3.46	0.38	2.67	4.26	NS†

* Significant ($p < 0.05$)
†NS – not Significant ($p > 0.05$)

Table 11. Color difference (Delta E) for thickness 0.7 mm vs. 1.0 mm as a function of stump shade

Stump Shade	n	ΔE	SE	Lower 95% CI	Upper 95% CI	P-Value
A1	10	2.38	0.23	1.86	2.90	NS†
A3	10	1.79	0.19	1.34	2.24	NS†
C4	10	1.31	0.21	0.83	1.79	NS†
Total	30	1.83	0.14	1.53	2.12	NS†

† NS – not Significant ($p > 0.05$)

Table 12. Pairwise comparisons in color differences (Delta E) for ceramic thickness (0.4mm, 0.7mm, 1.0mm) and stump shade (A1, A3, C4)

Ceramic Thickness (mm)			Delta E	SE	Lower 95% CI	Upper 95% CI	P-Value
0.40	VS.	**0.70**	0.27	0.17	-0.07	0.03	NS†
0.40	VS.	**1.00**	0.54	0.23	0.07	0.38	NS†
0.70	VS.	**1.00**	0.64	0.07	0.49	1.07	NS†
Stump Shade			**Delta E**	**SE**	**Lower 95% CI**	**Upper 95% CI**	**P-Value**
A1	VS.	**A3**	2.31	0.12	2.07	4.35	NS†
A1	VS.	**C4**	7.45	0.17	7.10	14.70	$p < 0.05$
A3	VS.	**C4**	5.32	0.15	5.01	10.40	$p < 0.05$

†NS – not Significant ($p > 0.05$)

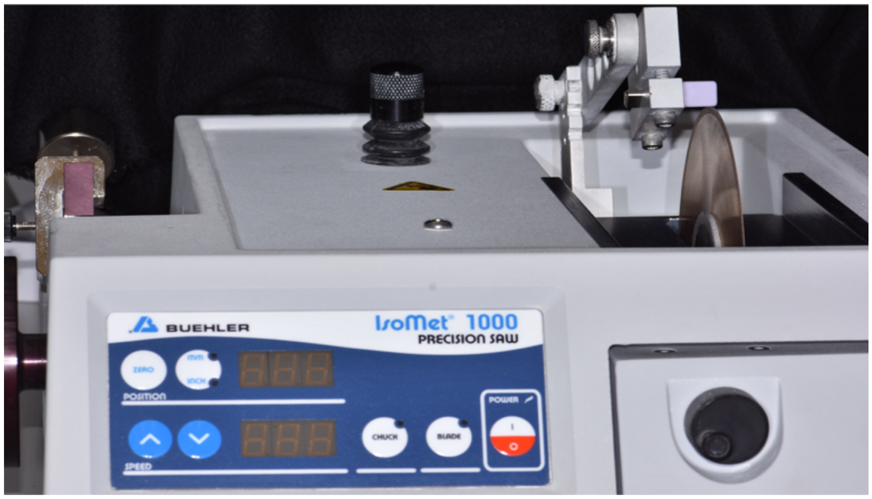


Figure 3. IsoMet® 1000 (Buehler ITW, Lake Bluff, IL, USA)

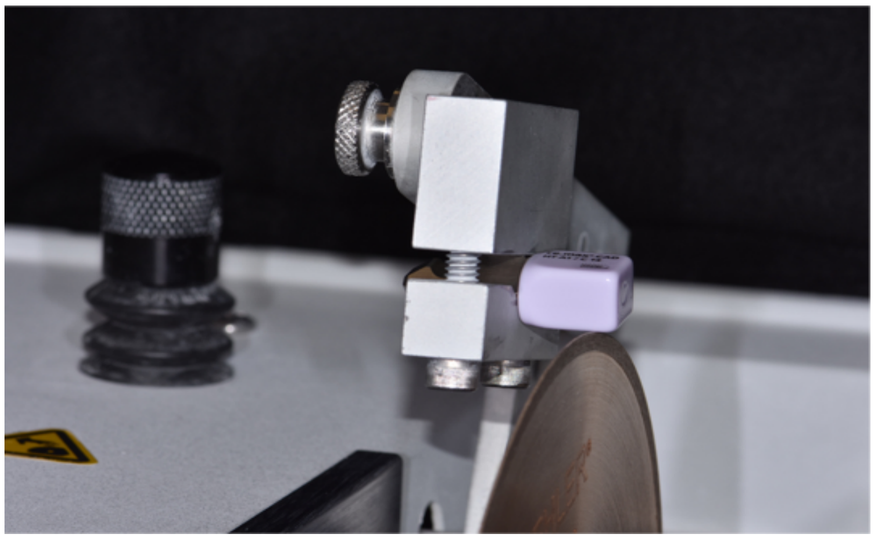


Figure 2. Adjusting the Ceramic Block into IsoMet® 1000 (Buehler ITW, Lake Bluff, IL, USA)

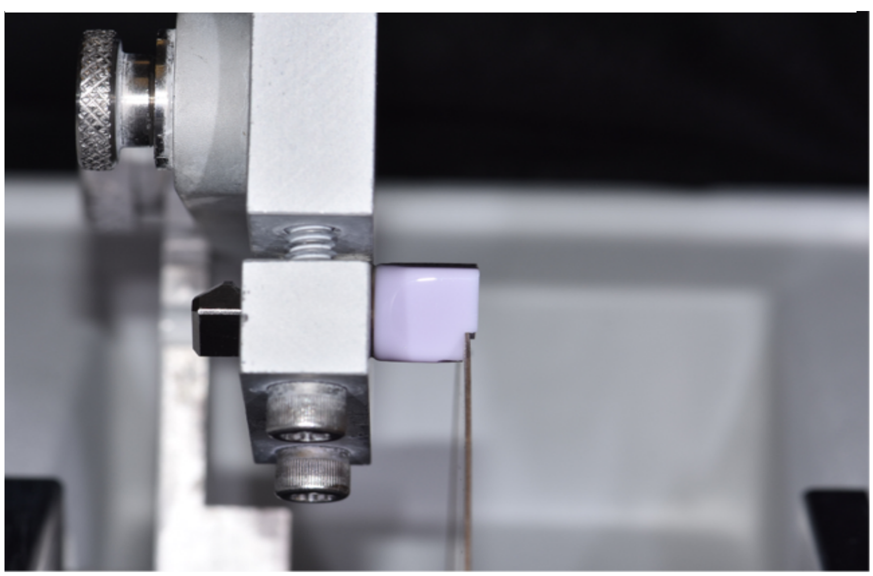


Figure 1. Waffering Blade 7X0.25X0.5 20HC (Buehler ITW, Lake Bluff, IL, USA)

Figure 4. Caliper to Measure the Ceramic Thickness of 0.4mm

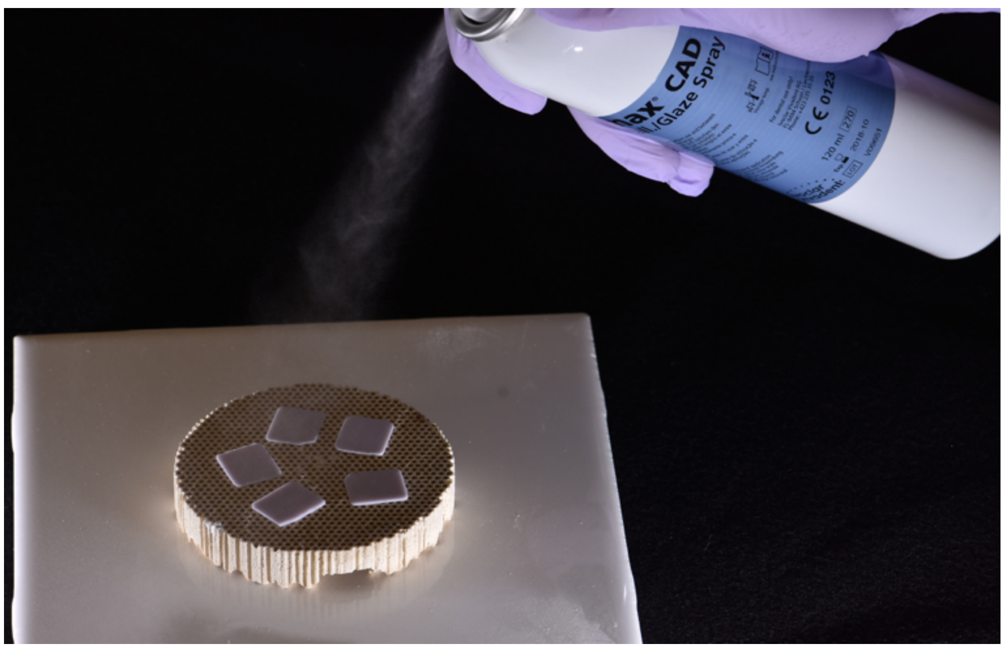


Figure 5. Neutral-Shade Glaze (Ivoclar Vivadent, Amherst, NY, USA)

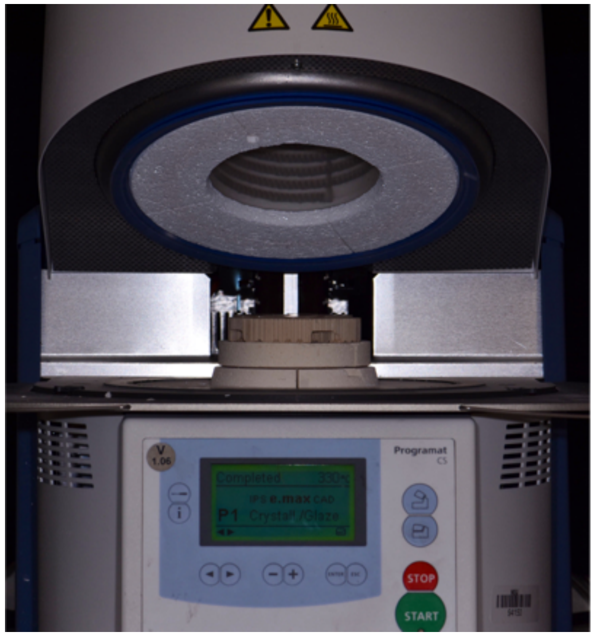


Figure 6. Ivoclar Vivadent Ceramic Furnace

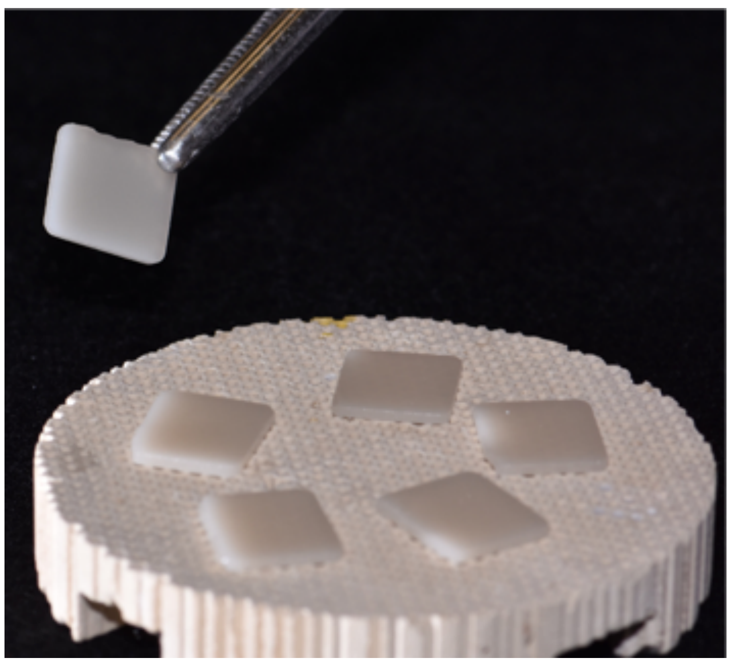


Figure 7. Ceramic Slice after firing at 765 °C

Figure 8. E.max Slice used to make a Custom-made mold to Fabricate Slice-Shaped Composite

Figure 10. Slice-Shaped Composite Fabrication (Filtek Supreme, 3M ESPE, St Paul, MN, USA)

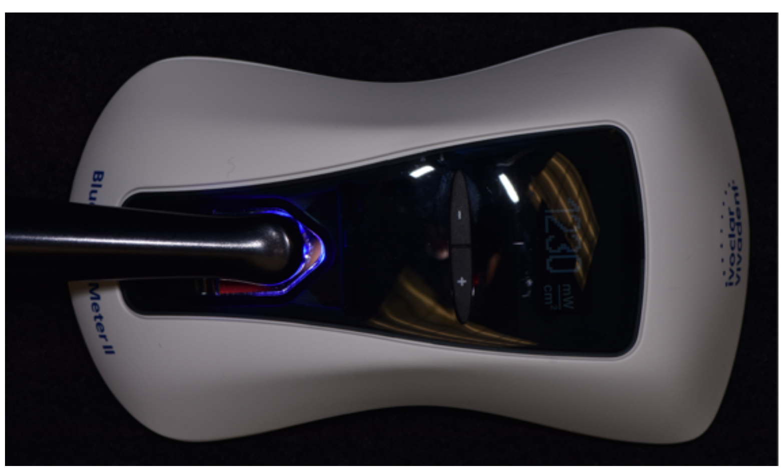


Figure 9. Dental Radiometer for Adjusting the Light Intensity of the Curing Unit to 600 mW/cm2

Figure 11. Application of 1st Composite Layer (Filtek Supreme, 3M ESPE, St Paul, MN, USA)

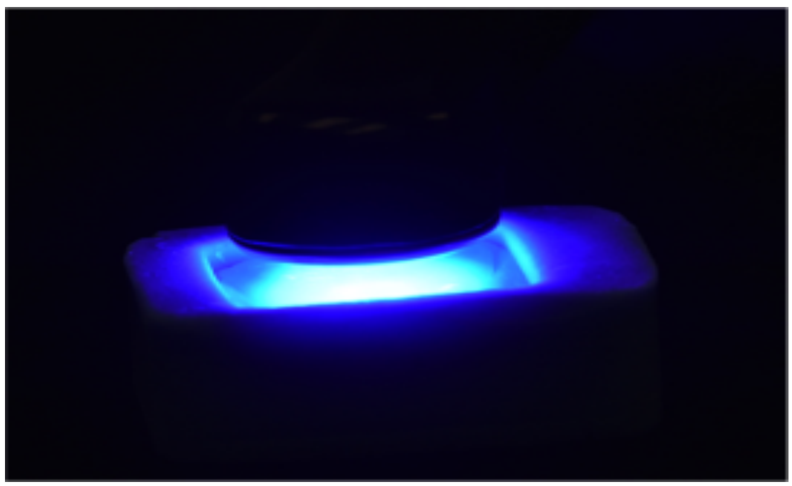


Figure 12. Composite 1st Layer Curing for 40 Seconds

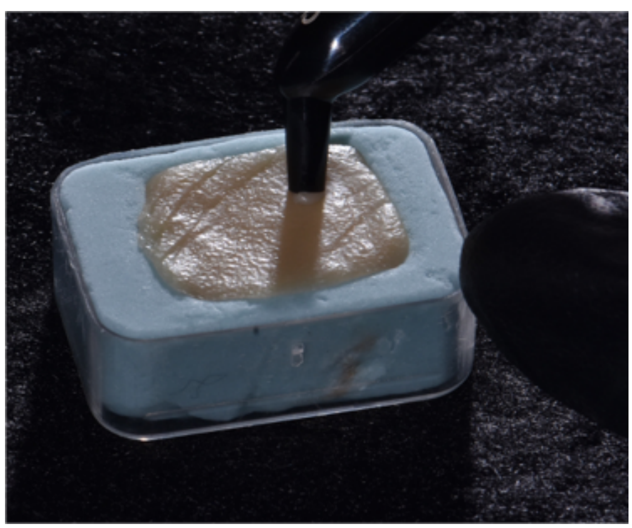


Figure 13. Application of 2nd Composite Layer (Filtek Supreme, 3M ESPE, St Paul, MN, USA)

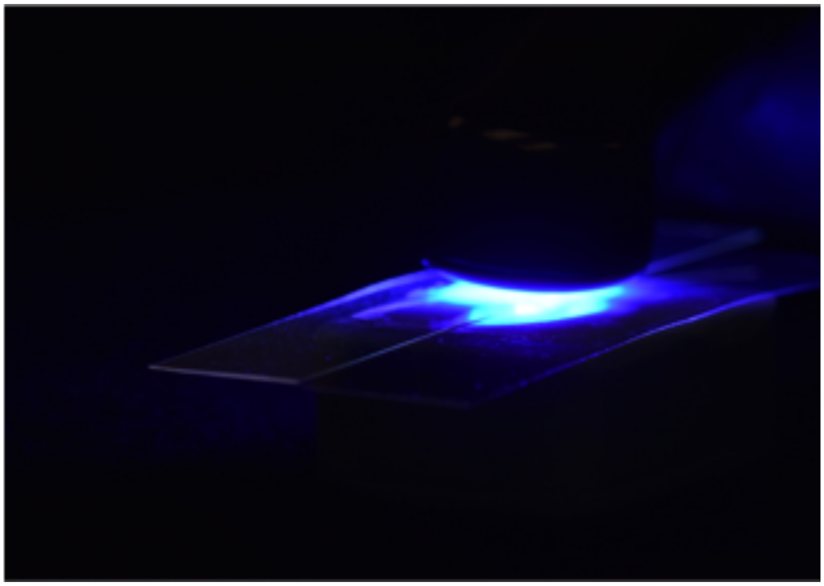


Figure 14. Composite 2nd Layer Curing for 40 Seconds through Mylar strips

Figure 15. Slice-Shaped Composite (Filtek Supreme, 3M ESPE, St Paul, MN, USA)

Figure 16. MetaServ® 2000 (Buehler ITW, Lake Bluff, IL, USA)

Figure 18. Composite Slice Before Finishing & Polishing

Figure 17. Composite Slice After Finishing & Polishing

Figure 19. Variolink Esthetic Cement, Neutral shade (Ivoclar Vivadent, Amherst, NY, USA)

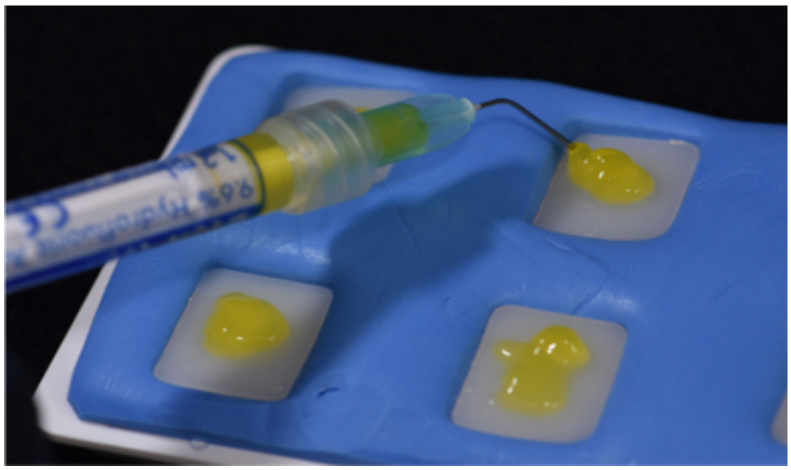


Figure 20. Ceramic Veneer Slices Pre-Cementation Process, Hydrofluoric Acid Application for 15 Seconds

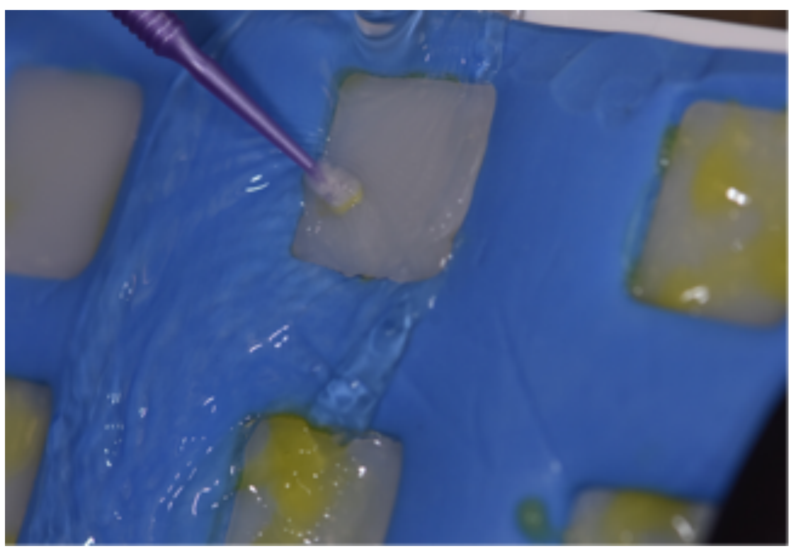


Figure 21. Ceramic Veneer Slices Pre-Cementation Process, Rinsing of Hydrofluoric Acid

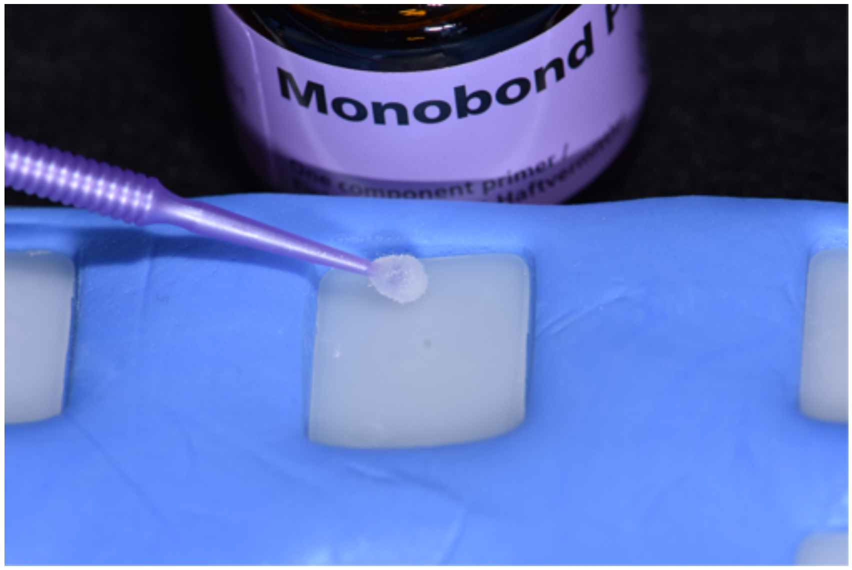


Figure 22. Application of Silane to the Inner Surfaces of the Veneer (Monobond Plus, Ivoclar Vivadent, Amherst, NY, USA)

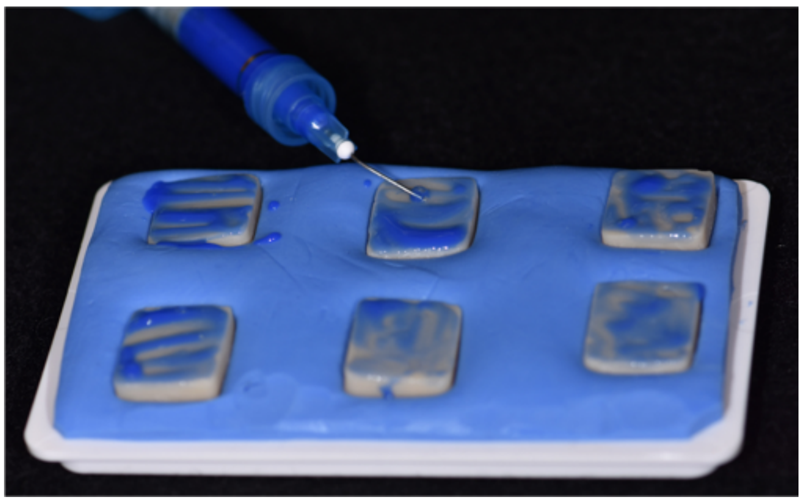


Figure 23. Composite Slices Pre-Cementation Process, Application of 37% Phosphoric Acid

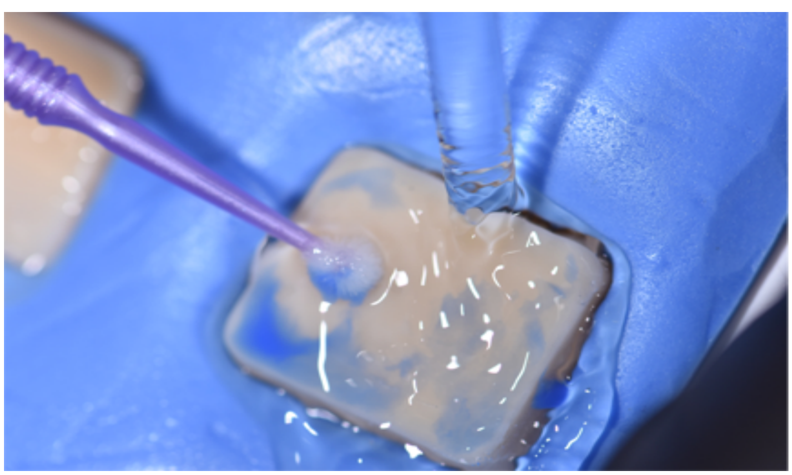


Figure 24. Composite Slices Pre-Cementation Process, Rinsing of Phosphoric Acid

Figure 25. Application of Bonding Agent (OptiBond™ FL, Kerr Corporation, Orange, CA, USA)

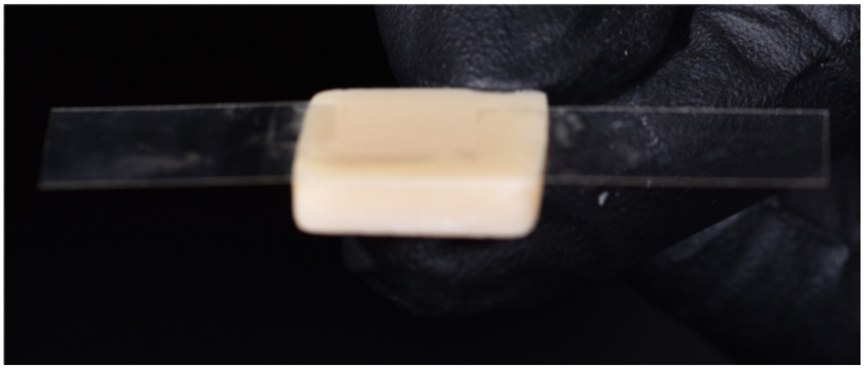


Figure 26. Cementation Process, Positioning of Mylar Strip

Figure 27. Cementation Process, Application of Resin Cement

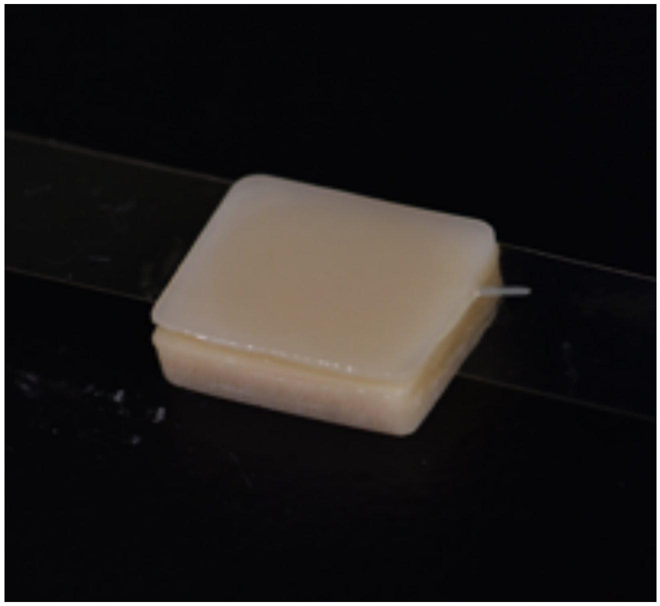


Figure 28. Cementation Process, Positioning of Ceramic Slice in top of the Resin Cement

Figure 29. Metlab Sample Leveling Press Device

Figure 30. One Hundred Twelve and Half Gram Weight

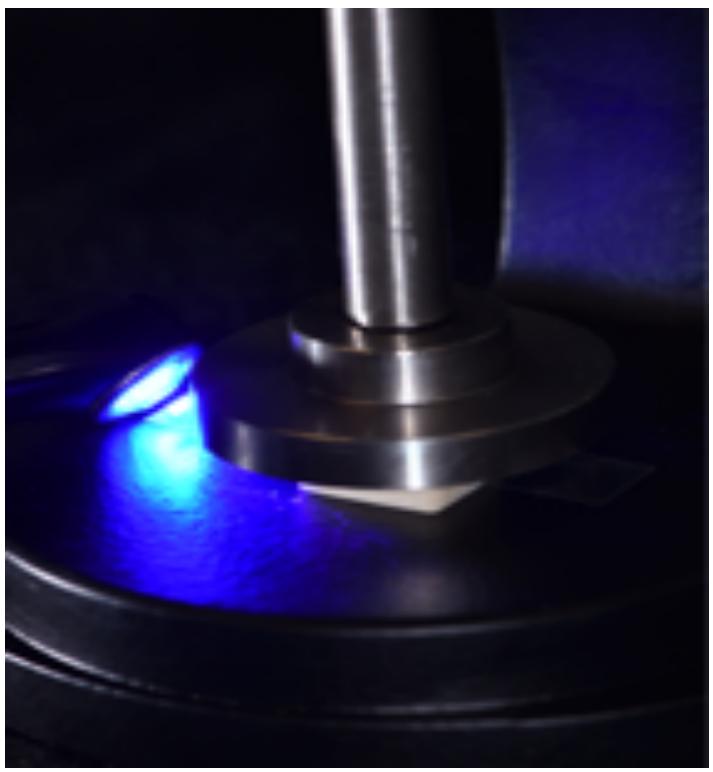


Figure 31. One Hundred Twelve and Half Gram Weight was Positioned over the Whole Unit

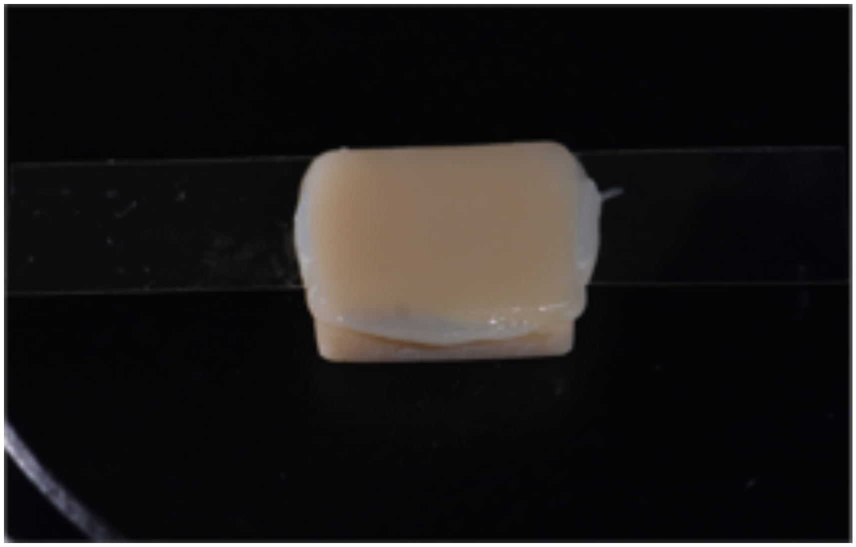


Figure 32. Specimen Before Removal of Excess Cement

Figure 33. Specimen After Removal of Excess Cement

Figure 34. Spectrophotometer, Gretag Macbeth Color-Eye® 7000A

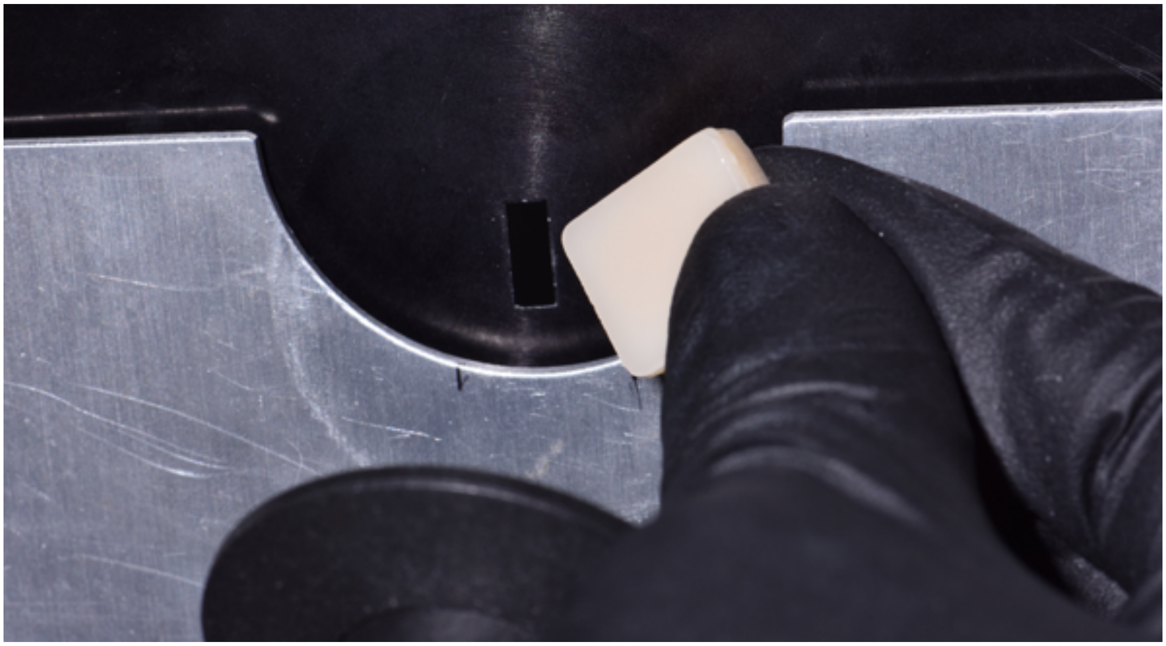


Figure 35. Positioning of Specimen into Spectrophotometer

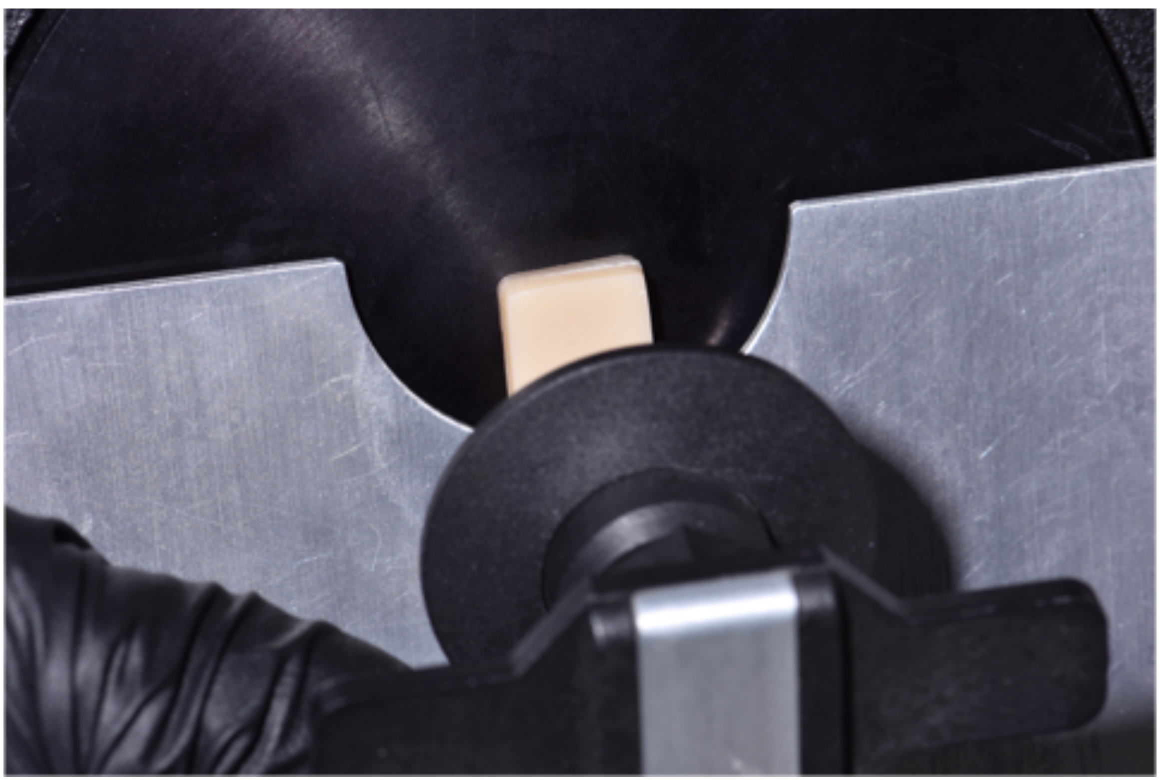


Figure 36. Specimen Color Measurement

Figure 37. Pairwise Comparisons of Color Difference (Delta E Values) Between Sample Groups Based Upon Ceramic Thickness and Stump Shade

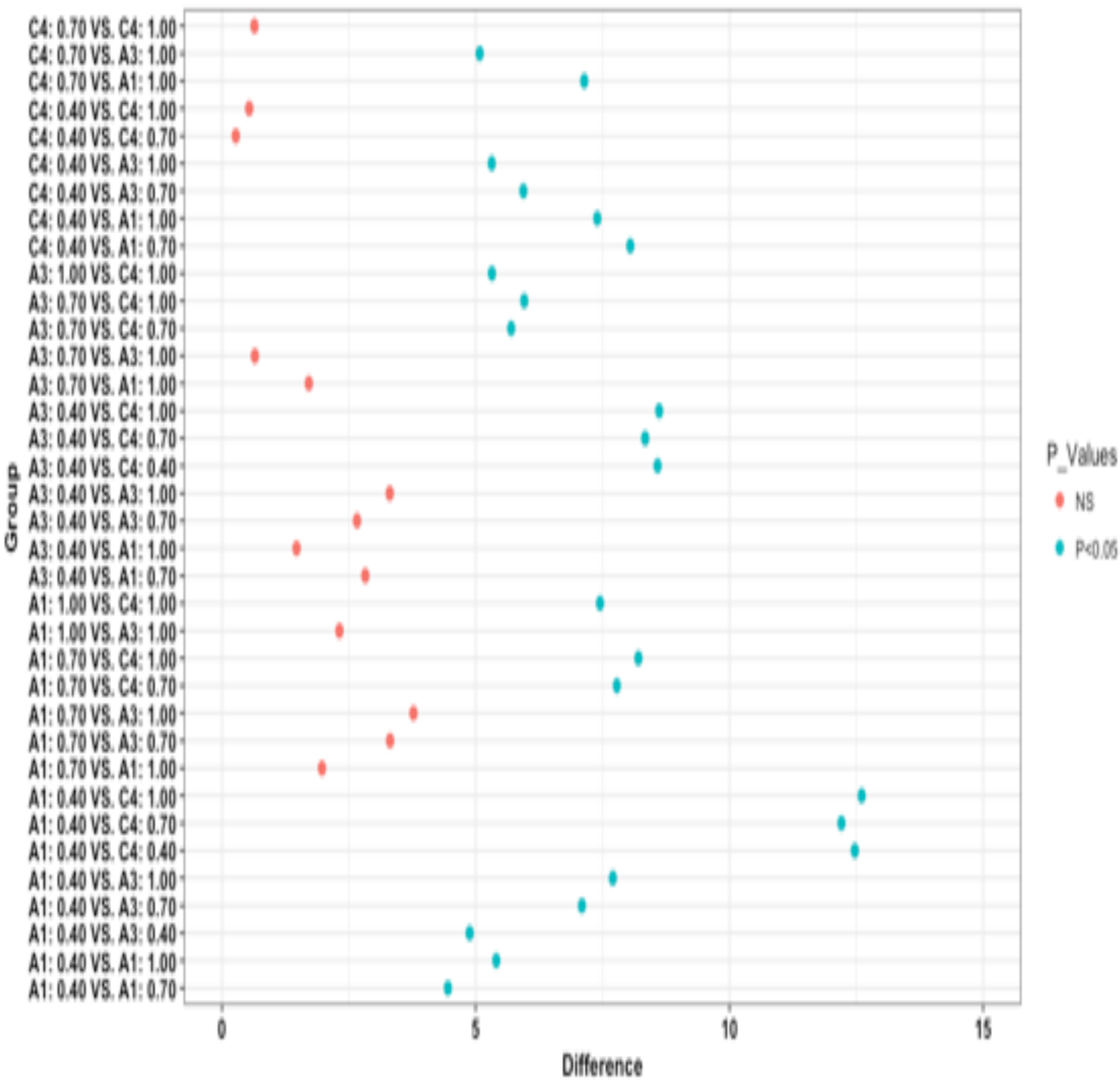
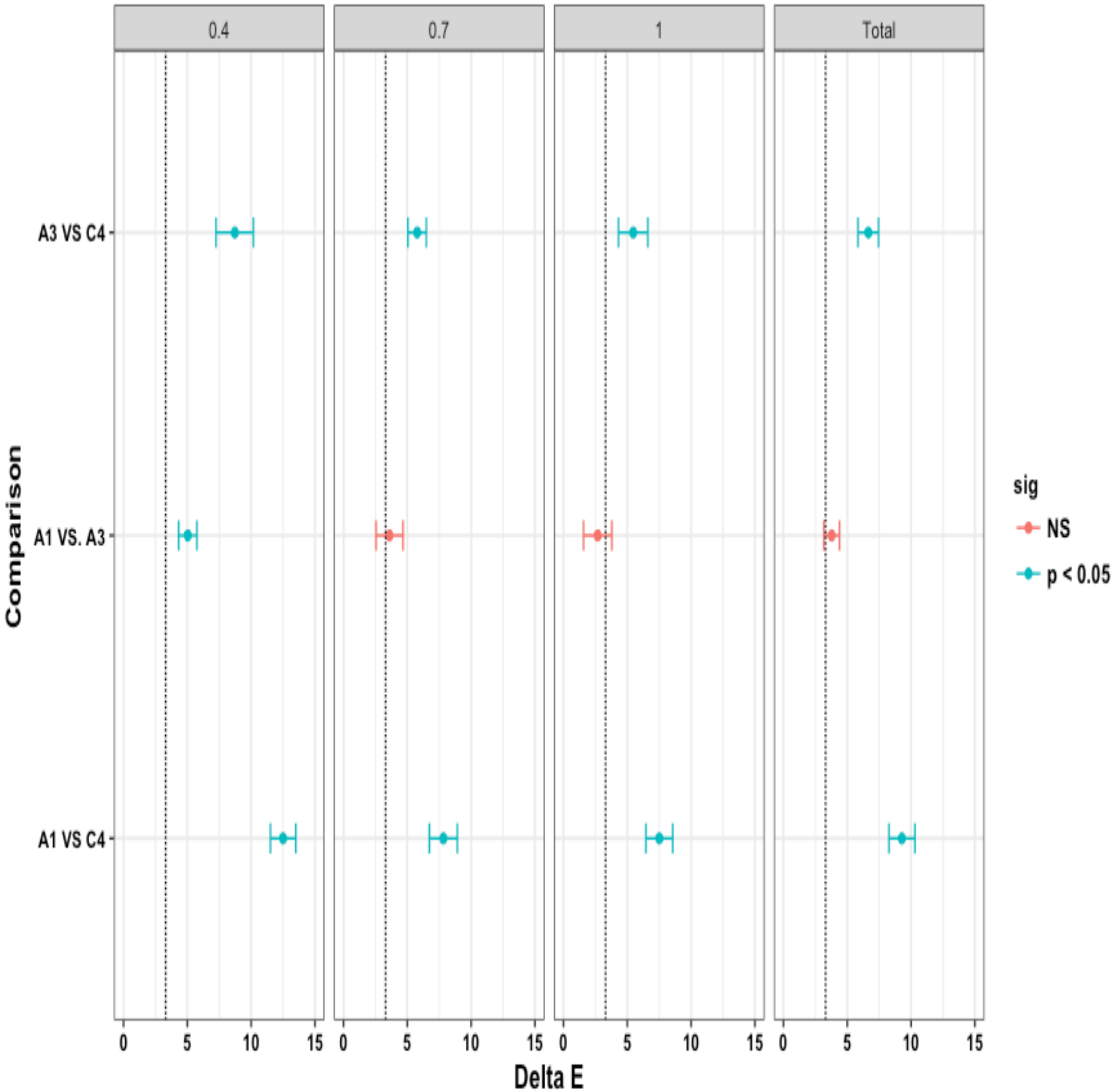


Figure 38. Comparison of Delta E by Stump Shade and Ceramic Thickness



Appendix A: Raw Data for Group 1

ID	Stump Shade	Ceramic Thickness (mm)	L*	a*	b*	△E
1	A1	0.40	64.82	-0.42	7.44	65.25
2	A1	0.40	65.23	-0.59	7.20	65.63
3	A1	0.40	63.29	-0.58	6.92	63.67
4	A1	0.40	64.51	-0.67	7.87	64.99
5	A1	0.40	63.53	-0.67	6.89	63.91
6	A1	0.40	63.69	-0.66	6.75	64.05
7	A1	0.40	64.54	-0.89	7.24	64.95
8	A1	0.40	64.23	-0.68	6.10	64.52
9	A1	0.40	63.06	-0.64	7.32	63.49
10	A1	0.40	63.77	-0.69	6.91	64.15

Appendix B: Raw Data for Group 2

ID	Stump Shade	Ceramic Thickness (mm)	L*	a*	b*	△E
11	A3	0.40	62.49	0.71	9.41	63.20
12	A3	0.40	60.15	0.52	8.42	60.74
13	A3	0.40	57.76	0.23	7.25	58.21
14	A3	0.40	58.78	0.17	5.41	59.03
15	A3	0.40	59.17	0.47	7.72	59.67
16	A3	0.40	58.38	0.39	7.78	58.90
17	A3	0.40	59.67	0.36	6.91	60.07
18	A3	0.40	59.62	0.45	7.10	60.04
19	A3	0.40	59.48	0.24	7.26	59.92
20	A3	0.40	57.58	0.30	6.67	57.97

Appendix C: Raw Data for Group 3

ID	Stump Shade	Ceramic Thickness (mm)	L*	a*	b*	△E
21	C4	0.40	52.43	-0.55	1.27	52.45
22	C4	0.40	51.32	-0.28	2.04	51.36
23	C4	0.40	53.01	-0.17	2.04	53.05
24	C4	0.40	52.54	-0.32	1.89	52.57
25	C4	0.40	53.10	-0.26	3.43	53.21
26	C4	0.40	54.82	-0.48	1.12	54.83
27	C4	0.40	51.90	-0.10	3.49	52.02
28	C4	0.40	52.44	-0.59	0.62	52.45
29	C4	0.40	51.60	-0.25	2.32	51.65
30	C4	0.40	53.64	-0.49	1.66	53.67

Appendix D: Raw Data for Group 4

ID	Stump Shade	Ceramic Thickness (mm)	L*	a*	b*	△E
31	A1	0.70	61.87	-0.61	7.26	62.30
32	A1	0.70	60.21	-0.64	4.60	60.39
33	A1	0.70	59.05	-0.79	3.86	59.18
34	A1	0.70	59.83	-0.64	5.17	60.06
35	A1	0.70	59.95	-0.65	4.88	60.15
36	A1	0.70	59.61	-0.64	5.23	59.84
37	A1	0.70	60.44	-0.61	5.33	60.68
38	A1	0.70	60.68	-0.67	4.85	60.88
39	A1	0.70	59.55	-0.80	3.78	59.68
40	A1	0.70	60.47	-0.70	4.24	60.62

Appendix E: Raw Data for Group 5

ID	Stump Shade	Ceramic Thickness (mm)	L*	a*	b*	△E
41	A3	0.70	55.39	0.05	4.68	55.59
42	A3	0.70	58.53	0.25	6.44	58.88
43	A3	0.70	57.29	-0.04	4.75	57.49
44	A3	0.70	56.74	0.09	5.87	57.04
45	A3	0.70	55.91	0.22	6.74	56.32
46	A3	0.70	58.44	0.22	6.37	58.79
47	A3	0.70	56.53	0.02	5.99	56.85
48	A3	0.70	56.96	0.04	5.84	57.26
49	A3	0.70	57.65	0.07	5.76	57.94
50	A3	0.70	57.65	0.22	6.75	58.04

Appendix F: Raw Data for Group 6

ID	Stump Shade	Ceramic Thickness (mm)	L*	a*	b*	△E
51	C4	0.70	51.72	-0.45	1.94	51.76
52	C4	0.70	53.27	-0.35	2.07	53.31
53	C4	0.70	53.37	-0.30	2.71	53.44
54	C4	0.70	52.66	-0.52	1.51	52.68
55	C4	0.70	52.72	-0.36	2.28	52.77
56	C4	0.70	53.20	-0.39	2.15	53.24
57	C4	0.70	52.56	-0.52	1.64	52.59
58	C4	0.70	54.72	-0.47	1.87	54.75
59	C4	0.70	52.57	-0.33	2.97	52.65
60	C4	0.70	52.44	-0.50	1.75	52.47

Appendix G: Raw Data for Group 7

ID	Stump Shade	Ceramic Thickness (mm)	L*	a*	b*	△E
61	A1	1.00	58.34	-0.41	6.55	58.71
62	A1	1.00	59.30	-0.49	6.16	59.62
63	A1	1.00	57.03	-0.52	6.55	57.41
64	A1	1.00	58.31	-0.51	6.10	58.63
65	A1	1.00	58.13	-0.55	5.66	58.41
66	A1	1.00	56.95	-0.58	6.02	57.27
67	A1	1.00	59.56	0.46	5.88	59.85
68	A1	1.00	60.35	-0.56	7.02	60.76
69	A1	1.00	59.53	0.65	6.28	59.86
70	A1	1.00	59.89	-0.54	6.05	60.20

Appendix H: Raw Data for Group 8

ID	Stump Shade	Ceramic Thickness (mm)	L*	a*	b*	△E
71	A3	1.00	56.35	-0.05	5.18	56.59
72	A3	1.00	56.62	0.09	5.44	56.88
73	A3	1.00	57.85	-0.04	5.02	58.07
74	A3	1.00	58.18	0.22	6.52	58.54
75	A3	1.00	55.48	0.04	5.09	55.71
76	A3	1.00	55.97	0.08	5.90	56.28
77	A3	1.00	58.58	0.21	6.04	58.89
78	A3	1.00	55.59	-0.01	5.15	55.83
79	A3	1.00	55.63	-0.08	5.92	55.94
80	A3	1.00	55.08	0.10	6.02	55.41

Appendix I: Raw Data for Group 9

ID	Stump Shade	Ceramic Thickness (mm)	L*	a*	b*	△E
81	C4	1.00	52.50	-0.47	2.66	52.57
82	C4	1.00	51.78	-0.57	2.56	51.85
83	C4	1.00	52.36	-0.57	2.42	52.42
84	C4	1.00	51.30	-0.48	2.52	51.36
85	C4	1.00	53.35	-0.59	2.01	53.39
86	C4	1.00	53.57	-0.56	2.45	53.63
87	C4	1.00	50.95	-0.51	2.46	51.01
88	C4	1.00	52.00	-0.50	2.50	52.06
89	C4	1.00	52.86	-0.61	1.91	52.90
90	C4	1.00	52.99	-0.58	2.27	53.04

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