The Effects of Cigarette Smoking on the Shade of CAD/CAM Restorations

BY

Stuart R. Schelkopf
B.S., University of Illinois at Champaign-Urbana, 2010
D.D.S., University of Illinois at Chicago, Chicago, 2014

THESIS

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Thesis Committee

Dr. Judy Yuan, Chair and Advisor
Dr. Cortino Sukotjo
Dr. Alvin Wee, Creighton University
Dr. Valentim Barao, University of Campinas

This thesis is dedicated to the numerous mentors that have allowed me an educational experience for which I will forever be grateful. It is due to their contribution that I have been able to enjoy my academic tenure, and I look forward to a life of fulfillment dedicated to providing care of the highest quality to the patients that I am so fortunate to treat.

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CAD	Computer Aided Design
CAM	Computer Aided Milling
COD	College of Dentistry
PFM	Porcelain Fused to Metal
PMMA	Polymethyl Methacrylate
SPSS	Statistical Package for the Social Sciences
UIC	University of Illinois at Chicago

SUMMARY

Introduction:

Digital dentistry has led to an inevitable shift in the paradigm of dental materials used for indirect restorations. There is a lack of information about the properties of these materials, such as color stainability, in the literature. Exposure to different agents can lead to staining of the external film of materials, leading to esthetic variability between restorative materials. Cigarette smoke has been shown to stain dental materials that are commonly used today.

Purpose:

The purpose of this study is to investigate the color stainability of CAD Lithium Disilicate (Ivoclar Vivadent e.max), monolithic CAD zirconia, as well as CAD acrylate polymer PMMA (Telio) when exposed to cigarette smoke. The null hypothesis states that the ΔE values before and after exposure to smoke and ageing will not differ within the following isolated groups as well as between the different surface finishes of the same material groups:

a. Lithium disilicate (e.max) glazed
b. Lithium disilicate (e.max) polished
c. Zirconia glazed
d. Zirconia polished
e. Telio PMMA

Materials and Methods:

Materials preparation

In this study, 100 discs (each 2mm thick) were prepared of 5 different CAD/CAM surface-finish (lithium disilicate glazed, lithium disilicate polished, zirconia glazed, zirconia polished and acrylate polymer). Each material produced 20 discs.

The materials were glazed and polished according to the manufacturer's recommendations. The experimental diagram is described in Figure 1.

Color Measurement

The baseline color measurement was performed using a spectroradiometer, and the spectral data was converted to CIELAB values.

The specimens were divided into 2 groups: control and experiment. The experiment samples were subjected to conditions simulating cigarette smoking, similar to what a restoration would be exposed to in an oral environment of a person smoking cigarettes.

The control specimens were stored in saliva-resembling conditions. After the exposure, color measurement were performed in the same way as baseline color measurement and color change (ΔE) was calculated before and after the intervention using the L*a*b values to quantitatively analyze the shade difference of each treatment group.

Results:

For the color change seen in the experimental samples between baseline and after smoking, mean ΔE values ranged from 12.8 to 19.2. The highest mean ΔE value was seen in the e.max (polished) sample with a value of 19.2 +/- 4.8. These experimental values can be compared against the corresponding control samples, which had mean ΔE values

ranging from 1.3 - 5.0. All samples exposed to cigarette smoke resulted in a higher mean color change compared to corresponding samples subjected to ageing only.

The brushing of the specimens led to the removal of excess gross smoke residue that remained on the surfaces. In measuring the color change between the post-smoking measurements and the post-brushing measurements, mean ΔE values ranged from 13.7 to 20.3. These experimental values can be compared against the corresponding control samples, which had mean ΔE values ranging from 0.7 to 2.9.

The final color change data that was quantitatively analyzed was the overall color change from the baseline measurements to the post-brushing measurements. These mean ΔE values ranged from 2.5 to 9.6. The polished zirconia sample demonstrated the largest mean ΔE value, 9.6 +/- 1.8, while the glazed e.max samples had the smallest overall color change, with mean ΔE values of 2.5 +/- 0.4. These experimental values can be compared against the corresponding control samples, which had mean ΔE values ranging from 0.7 to 4.3. Based on our study, cigarette smoke exposure led to greater mean color change for all samples, independent of surface finish, compared to corresponding control samples exposed only to ageing solution.

Discussion and Conclusion:

The following conclusions were drawn from the results of our studies:

I. When exposed to cigarette smoke, the CAD/CAM available materials of lithium disilicate, zirconia, and Telio are all susceptible to staining.

II. The polished finish of e.max lithium disilicate does not lead to increased stainability when compared to the glazed surface of e.max lithium disilicate.

III. The polished finish of zirconia does not lead to an increased stainability when compared to the glazed surface of zirconia.

IV. After exposure to cigarette smoke, all restoration materials tested that are brushed with a toothbrush exhibit a decrease in staining.

1. INTRODUCTION

1.1 Background

The use of ceramics in restorative dentistry is highly popular in the modern era; however, ceramics have a long history that has allowed its evolution. Ceramics were first noted in civilization more than 10,000 years ago in the stone age.[1] It was not until the 18th century that the use of ceramics were recorded in dentistry though. Ceramics were first utilized in dentistry as a material for the use of dentures and denture teeth. In 1723, it was noted that "enameling of a metal denture base" was introduced by Pierre Fauchard.[2] In 1789, the first denture teeth fabricated in porcelain were described by a French dentist, De Chemant.[1] In the early 1800s, ceramics continued its application as Fonzi reported the development of "tetro-metallic incorruptibles." These "incorruptibles" were porcelain teeth impregnated with platinum pins.[1]

Finally, in the late 1800s and 1900s, the use of ceramics was applied to fixed restorative dentistry. In 1889, Charles H. Land reported the fabrication of an "all porcelain jacket crown".[3] This type of ceramic restoration consisted of porcelain application directly to a die to fabricate a porcelain "jacket" to restore missing tooth structure. Due to the heating and cooling during fabrication, internal cracks were reported in the restorations, leading to weakened structure and failure.[4] Throughout the early 1900s, this restoration and the technique to produce it were evolved to minimize its flaws. Then, in the 1950s, Abraham Weinstein introduced the porcelain fused to metal (PFM) restoration to overcome the weak structural integrity of the porcelain jacket crowns.[4]

The PFM crown consisted of a thin metal coping for increased strength and support of the applied porcelain that was baked onto its surface to the full contour of the restoration. Esthetic concerns were associated with these early PFM restorations though,

as the dark metal tended to show through the porcelain, creating a lower value of the overall restoration.[2]

To overcome this dark esthetic appearance, all-ceramic restorations continued to be developed for improved esthetics and biocompatibility.[5-7] Aluminous porcelain was introduced in the 1960s. Aluminous porcelain (porcelain impregnated with 40-50% alumina crystals) was applied as an internal coping, and feldspathic porcelain was applied to the outside full contour of the restoration. These restorations presented with an opaque appearance though, leading to esthetic failure as well.[8] The strength of these restorations was reported higher than traditional jacket crowns, but strength was still remained as a concern for these all ceramic restorations. All-ceramic restorations continued to be developed with incorporations of mica and leucite to overcome the inherent strength and esthetic deficiencies. IPS introduced Empress ceramics in the 1980s, which was a leucite reinforced porcelain that was heated and pressed to fabricate the restorations using a lost wax technique.[9,10]

Vita introduced the In-Ceram system as well, which utilized the slip-casting technique to fabricate ceramic restorations with 85% sintered alumina.[8] Ceramic systems with spinel (MgAl2O4) as well zirconium oxide crystals were also created to increase the flexural strength of the materials.[11,12]

Until this point in history, ceramic materials had several key shortcomings that stemmed from the technique sensitivity of the fabrication of the restorations as well as the heating and cooling of the ceramics in order to manufacture the final product.[5] These inherent issues led to deficiencies in esthetics and flexural strength as well as a high level of skill necessary by the technician to create a high-quality restoration.[13]

Finally, in the late 20th century, the advent of computer-aided technology in dentistry allowed for new materials to be introduced. Due to computer-aided design (CAD) and computer-aided milling (CAM), ceramic materials no longer needed to be available for hand-manipulation in order to build, fire, and crystallize ceramic restorations.[14] Materials such as silica-based ceramics, infiltration ceramics, oxide high performance ceramics, and methacrylate-based polymers could be mass produced in ingots, leading to higher levels of homogeneity and increased consistency.[15] With the advent of CAD/CAM technology, high-strength materials such as zirconia, which were previously unusable due to the structural lattice conformation, could now be prefabricated and milled to create restorations.[16]

Within the CAD-available materials, Telio exists as an already-polymerized PMMA material for provisional restorations. These CAD-available ingots provide advantages over traditionally polymerized PMMA that is fabricated through the mixing of open chain PMMA polymer and monomer. Such advantages include flexural strength enhancement, stain resistance, and intra-material consistency, as the inconsistencies from mixing of components is eliminated. Also, the CAD process of fabricating these restorations bypasses polymerization shrinkage, a common clinical disadvantage of PMMA utilization. With conventionally mixed and prepared PMMA materials, increased error, porosity, and inconsistency leads to decreased homogeneity within the materials. This decrease in homogeneity further increases the susceptibility to staining. However, due to the highly-controlled, high pressure environment when preparing CAD/CAM-available PMMA material blocks, modern CAD/CAM-available PMMA blocks exhibit greater consistency within the polymerized matrix, further decreasing the susceptibility to both mechanical and esthetic failure, such as fracture and staining.[17]

One of the most popular CAD/CAM available final restorative materials used today in dentistry is CAD lithium disilicate. Lithium disilicate was first introduced in 1988 as IPS Empress 2, a material that could be pressed.[18] Today, the lithium disilicate ceramic has evolved to develop today's restorative material IPS e.max, which it is both pressed and milled.[18,19] The fabrication of e.max restorations uses a two-stage crystallization process involving a controlled double nucleation process where lithium meta-silicate crystals are precipitated during the first step.[19,20] In the second heat treating step performed after the milling process, the meta-silicate phase is completely dissolved and the lithium disilicate crystallizes. The final composition of the microstructure of the lithium disilicate is $Li_2Si_2O_5$.[20,21] This heat treatment occurs at approximately 840-850 degrees Celsius, and processing results in a .5-2micron fine-grain glass ceramic composed of 70% crystal volume in the glass matrix.[20]

Another popular CAD/CAM available material often used for restorations is Yttria-stabilized zirconia (zirconium dioxide). Until computer-aided technology, the application of zirconia in restorative dentistry had only included incorporation of zirconium oxide crystals embedded in ceramic matrices for increased strength. However, the true advantage of zirconia lies in its crystal lattice conformation though, which leads to the reported elevated flexural strength of 750-1000MPa of the material.[15,22,23] Zirconia used in the dental field is generally a yttria (Y_2O_3) tetragonal zirconia polycrystal (Y-TZP). Yttria is an oxide that is added to stabilize the crystalline structure of the zirconia throughout firing and sintering.[24] In relation to modern dental practice, zirconia powders are prepared and used by the manufacturers to press and fabricate pre-sintered blanks. These pre-sintered blanks are then made available to dental labs and private practitioners to be used for milling CAD restorations. After machining and milling the restorations, the

high-strength zirconia is then colored and finished with the application of stains and glaze and subsequently sintered at approximately 1350-1530 degrees Celsius.[25-27]

Clinically, Ivoclar Vivadent recommends the e.max CAD restorations to be tried in intraorally and adjusted in the post-milling blue stage prior to final glazing and crystallization. Similarly, the zenostar zirconia CAD restorations are to be tried in intraorally in the green stage and adjusted prior to final glazing and sintering.[22] After final crystallization or sintering, Ivoclar's protocol instructs that any additional adjustment to the restoration should include polishing to minimize the resulting roughness of the surface. Adjustments and polishing after crystallization and sintering leads to removal of the glazed external surface of the restoration, which has a reported roughness below .2μm.[28] Polishing of the surface, therefore effectively removing the glazed layer, results in exposure of the unglazed ceramic, associated with higher reported roughness values. This increase in surface roughness can lead to changes in the properties of restorative materials, including increase in stainability.[28]

Material selection in restorative dentistry has become more complex with the abundance of restorative material options available today.[29] In the past, restorations that were hand-fabricated with the building of feldspathic porcelain were most commonly used in dentistry; however, this paradigm is quickly shifting with CAD/CAM-available materials gaining popularity, such as CAD lithium disilicate (Ivoclar Vivadent IPS e.max) and monolithic zirconia.[1] The monolithic CAD/CAM blocks offer a consistent standard quality when compared to the manually veneered technique and have become the preferred option.[2] Lower wear rate in the material and on enamel antagonists have been observed,[30] and fewer material interfaces produce less mechanical complications such as less porcelain chipping.[16,31-33] Due to the increased efficiency of CAD/CAM

technology coupled with the decreased cost of utilizing CAD/CAM available restorative materials, CAD/CAM's strong presence in the dental market is inevitable. However, various aspects of the properties of these materials have yet to be investigated.

One of the critical esthetic properties of restorative materials is color stability and stainability. Color in dental restorations is a highly involved science involving hue, chroma, and value balanced with translucency.[34] Hue is defined as "the basic color, hue is the quality of sensation according to which an observer is aware of the varying wavelengths of radiant energy. The dimension of color dictated by the wavelength of the stimulus that is used to distinguish one family of color from another—as red, green, blue, etc. The attribute of color by means of which a color is perceived to be red, yellow, green, blue, purple, etc. White, black, and grays possess no hue."[35] Chroma is "the purity of a color, or its departure from white or gray. It is the intensity of a distinctive hue; saturation of a hue."[35]Value is defined as the quality by which a light color is distinguished from a dark color, the dimension of a color that denotes relative blackness or whiteness (grayness, brightness). Value is the only dimension of color that may exist alone."[35] Finally, translucency is "having the appearance between complete opacity and complete transparency."[35] These four aspects of color differ greatly between different materials, and they can also differ between different ingots of the same material as well.

Color incorporation in ceramics is often embedded through the incorporation of coloring ions that change oxidation state upon temperature change. In IPS e.max, Vanadium, Cerium, and Manganese are three coloring ions that are proportioned throughout the ceramic to produce specific hues and chroma.[36] Under firing, the oxidation state of Vanadium, V^{+4}/V^{+3}, controls the blue/yellow balance, respectively. Similarly, the

oxidation state of cerium (Ce^{+4}) and Manganese (Mn^{+3}) contributes to the yellow and brown color of a ceramic, respectively.[36]

Intra-material color and translucency involves the light reflectivity throughout a material. This can be controlled by the lithium disilicate crystal size and matrix density. For instance, IPS e.max High Translucency (HT) ingot includes crystalline sizes of 1.5 x 0.8mm in a more glassy, less dense matrix, while Low Translucency (LT) ingot includes crystalline sizes of 0.8 x 0.2mm in a more dense arrangement.[37]

Color can also be incorporated externally to materials through external stain application. External stain application can occur during the processing of CAD/CAM restorations to clinically match a patient's adjacent dentition. Stain can also be unintentionally incorporated onto the external surface throughout a restoration's lifetime from exposure to various staining agents within the oral environment.

Color change on dental materials can occur in three different ways. In an oral environment, plaque accumulation and stain can collect on the external surface, leading to a change in the color of the surface. Changes on the surface and sub-surface, including surface degradation, also can promote the penetration of staining into a material, further leading to color change. Finally, physical changes to the matrix and structure of a material over time can lead to an internal color change of the material.[38-41]

In a world where dental restorations are constantly exposed to various staining agents such as cigarette smoking, particular medications, as well as coffee, tea, and red wine ingestion, color stainability is an important factor to best ensure the long term esthetic quality of treatment provided.[40,42] Extrinsic staining agents act on restorations by two different methods. The agents can permeate porous superficial surfaces, leading a stained appearance amongst the outer surface of the material.[43] The agents also act by

combining with salivary carbohydrates to leave a stained film on the materials surface.[38,44,45]

Today, one of the most common causes of extrinsic staining is due to cigarette smoking.[46] According to CDC.gov, in 2016, 15.5% of American adults smoke cigarettes on a daily basis.[47] In addition, the most recent survey by the World Health Organization in 2010, 22.1% of the population over 15 years old worldwide smoke tobacco.[48] This indicates that more than 1 billion people use tobacco. From this, it is obvious that cigarette smoking remains highly prevalent amongst today's population, and this habit greatly affects the long term esthetic outcomes of the treatment that our patients receive.

In past studies, the stainability of different agents have been investigated as well as the color stability amongst the various dental materials used historically, including layered porcelains, composite materials, and traditionally processed PMMA. With today's dynamic paradigm shift of material usage in dentistry favoring CAD/CAM-available materials, investigation and understanding of these same properties for modern materials is imperative to provide treatment for our patients with the best long-term esthetic prognosis, a comprehensive understanding of the properties of the most commonly selected dental materials.

CIE L*a*b* values are the standard parameters used to analyze and compare color in materials. The CIE L*a*b* system was first established by Richard Hunter in 1942 and adopted by the Commision Internationale d'Eclairage (CIE) in 1976.[49] This system uses three axes to evaluate and establish quantitative values for color analytics of a material. The L* is used to analyze the value or lightness on a greyscale, which higher values indicating a darker appearance. The a* measures the amount of red and green in an

object, with positive values indicating more red noted and negative values indicating more green. Finally, b* is used to measure the blue and yellow measured, where positive values indicate more yellow and negative values indicate more blue (Diagram A). [49] This color evaluation system allows for differentiation of individual colors within a material, value analysis of a material, as well as inter-material quantitative comparison through ΔE values. The CIE L*a*b* system also has relevance to human perception of color, further suggesting its applicability in clinical dentistry.[34] Through measurement of color using the quantitative CIE L*a*b* system, color difference can be measured and expressed as ΔE through the following equation:

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

This can be used to discuss color differences between different materials as well as the same material over time.[50] In relation to the human eye perceptibility of color difference (ΔE), values of 1.0-3.7 have been shown through research to be the perceptibility threshold with a generally accepted perceptibility threshold for color difference (ΔE) of 2.6. ΔE values of 1.7-6.8 have been reported for human eye acceptability threshold as well.[51]

It is apparent that color stability and stain resistance of traditional dental materials, such as acrylic denture teeth, dental composites, and feldspathic porcelain, have been widely investigated; however, this property of the indirect restorative materials that are most often used nowadays is yet to be studied. CAD/CAM-available materials (lithium disilicate, zirconia, and acrylate polymer) are rapidly gaining popularity, but the

existing studies providing insight into the relative long-term color stability and stainability of these materials is insufficient for a comprehensive understanding of their properties. Due to the high prevalence of cigarette smoking in our population in conjunction with the increased emphasis on esthetics today, color stainability of CAD/CAM restorations in relation to cigarette smoke exposure must be better studied and understood.

1.2 Significance

In the modern era, esthetics have grown to be a significant concern in regards to restorative dentistry. Patients are more attuned to the esthetics of their dentition and restorations. Although providers put forth the effort to achieve restorations that appear esthetically pleasing at the time of delivery, it is also imperative that these same restorations continue to appear esthetically pleasing throughout their lifetime. With the knowledge that we possess regarding potential for stainability of our restorations when exposed to external staining agents such as cigarette smoke, clinical providers must factor this material property into the decision when selecting a restorative material for a patient. Historically, color stability and stainability of our past materials have been explored in the literature; however, further investigation into the color stability and stainability of our modern CAD/CAM materials is needed. The significance of this research is to explore the stainability of various CAD/CAM materials that are available and frequently used today.

1.3 Specific Aims and Hypotheses

Aim #1: Investigation of the color stainability of CAD Lithium Disilicate (Ivoclar Vivadent e.max), monolithic CAD zirconia, and CAD acrylate polymer PMMA (Telio) when exposed to cigarette smoke.

Null Hypothesis #1: The comparison of ΔE values of the CAD Lithium Disilicate (Ivoclar Vivadent e.max), monolithic CAD zirconia, and CAD acrylate polymer PMMA (Telio) will not display a significant difference between the control specimens that are submerged in artificial saliva and the test specimens that exposed to cigarette smoke.

Aim #2: Investigation and comparison of the color stainability of CAD Lithium Disilicate (Ivoclar Vivadent e.max) in both its polished and glazed state when exposed to cigarette smoke.

Null Hypothesis #2: The comparison of ΔE values of the CAD lithium disilicate in its glazed and polished state will not display a significant difference.

Aim #3: Investigation and comparison of the color stainability of monolithic CAD zirconia (Ivoclar Vivadent zenostar zirconia) in both its polished and glazed state when exposed to cigarette smoke.

Null Hypothesis #3: The comparison of ΔE values of the monolithic CAD zirconia in its glazed and polished state will not display a significant difference.

2. REVIEW OF LITERATURE

2.1 Lithium Disilicate

Lithium Disilicate glass ceramic material has become one of the most commonly used materials used for indirect restorations in dentistry today.[58,59] Lithium disilicate glass ceramic has a microstructure composition of Li_2Si_2O, and is composed of quartz, lithium dioxide, phosphor oxide, alumina, potassium oxide, and trace minerals.[20] This ceramic restorations combines high strength with biomimetic esthetics, biocompatibility, excellent wear properties, and the ability to etch and bond to dentin and enamel tooth structure. First introduced as the IPS Empress line from Ivoclar Vivadent, this material could be pressed in a lost-wax technique to produce full-contour ceramic restorations as well as lithium disilicate copings for porcelain layering.[18] In 2005, lithium disilicate-enforced ceramic was reintroduced as IPS e.max, which could be both pressed or milled using CAD/CAM technology. IPS E.max is a .5-2micron fine-grain glass ceramic composed of 70% crystal volume in the glass matrix,[20] resulting in a reported average flexural strength of greater than 400mPa.[20]

The absence of metal or high-opacity structures within the restoration results in the ability to achieve highly-esthetic results. The control of crystal size and crystal density allows for control of the material's opacity and translucency.[37] This leads to different opacity ingots within the e.max product line, with higher opacity ingots containing smaller crystal sizes and more densely-packed grains. As with other glass-ceramics, color-controlling oxidizing ions are able to be incorporated to control inherent color and chroma within the restoration as well. As previously noted, Vanadium, Cerium, and Manganese are three coloring ions that are incorporated within the ceramic powders to produce specific hues and chroma.[20] During firing, the oxidation state of Vanadium,

V^{+4}/V^{+3}, controls the blue/yellow balance, respectively. Similarly, the oxidation state of cerium (Ce^{+4}) and Manganese (Mn^{+3}) contributes to the yellow and brown color of a ceramic, respectively.[20]

With the advent of CAD/CAM technology, IPS e.max was released in prefabricated blocks for milling. Due to the ability of in-office and increased speed of restoration design and milling, this method of restoration production has become the most common use of lithium disilicate in the field of dentistry. Upon milling, firing, and glazing the lithium-disilicate, the restoration is ready for clinical insertion. Pre-insertion and post-insertion adjustment can then be completed with high and low speed clinical handpieces with the aid of polishing burs, as instructed by the manufacturer to achieve a fine polish upon finish.[60]

2.2 Zirconia

Yttria-stabilized zirconia (Zirconium Oxide) is a material that has gained popularity in recent decades as well due to the advent of computer-aided technology.[61-64] The crystal lattice conformation of zirconia allows for high strength with a glass-like esthetic appearance.[61] Yttria is an oxide that is added to stabilize the crystalline structure of the zirconia throughout firing and sintering.[24] Flexural strength values of 750-1000mPa have been routinely reported, lending itself as one of modern day's strongest indirect restoration materials.[15,23] Previously, zirconia's implication in dentistry was limited to embedment within ceramic matrices to increase the material's strength. With CAD/CAM technology, zirconia blocks are able to be pre-fabricated by the manufacturer and distributed to be used to mill restorations in-office or in dental laboratories.[61] Upon milling and sintering, the restorations can then be stained and glazed for a final glossy esthetic appearance. Similar to other ceramic restorations, zirconia can be minimally

adjusted and fine-polished to produce the final desired contours and occlusion of the restoration.[60]

2.3 Poly(Methyl Methacrylate) (PMMA)

One of the most commonly used materials in dentistry is poly(methyl methacrylate) (PMMA). PMMA has current uses in dentistry such as direct and indirect provisional restorations, final indirect restorations, denture and partial-denture bases, denture teeth, night guards, and surgical guides. Existing available materials used for provisionalization include polymethyl methacrylate (PMMA), polyethylene methacrylate, urethane mathacrylate , polyvinyl methacrylate, and bis-acryl.[65-67] With the advent of CAD/CAM technology, PMMA has been introduced as a pre-fabricated material available for milling of computer-designed restorations as provisional or prototype restorations.[68]

Traditionally, PMMA has been used due to its handling properties, esthetic appearance, and ability to withstand the force of mastication overtime.[1] PMMA powder can be mixed with methyl methacrylate monomer to polymerize, forming a rigid final PMMA product via a free radical polymerization reaction. In dentistry, this allowed for easy manipulation to form restorations. However, due to its high shrinkage of 7%, inefficient polymerization, and heterogeneity, PMMA existed with various drawbacks.[1]

When CAD/CAM was introduced as a technique to design and mill restorations, PMMA was introduced as pre-polymerized blocks for milling.[68] In order to overcome the pre-existing flaws of the traditional techniques for PMMA utilization, these PMMA blocks were polymerized under heat and pressure to improve polymerization saturation, and therefore homogeneity within the material and flexural strength.[67] This CAD/CAM method of milling restorations from pre-polymerized blocks overcomes the drawback of polymerization shrinkage as well.[68]

Although great improvements have been achieved with the use of PMMA with CAD/CAM technology, the inherent material properties of PMMA still remain less-than-ideal for a permanent restoration. Impact strength, porosity, and wear characteristics still remain inferior to other aforementioned materials, such as lithium disilicate ceramic or zirconia.[69,70,71]

2.4 Restoration Abrasion and Staining

The properties of a restoration are dynamic with inevitable change to a the material over time when subjected an in-vivo environment. Occlusal function, parafunctional wear, daily hygiene routine, and exposure to different foods and inhaled compounds can modify the surface of a restoration, resulting in microfractures, abraded surfaces, and staining. With these resulting modifications, the properties of a restoration are changed, differing from the initial properties of the inserted glazed, unstained, intact restoration.

Following final production of a dental restoration, exposure to abrasive and staining agents is inevitable. When ceramic restorations are produced, they are coated with a glaze in order to seal the open pores after a porcelain is fired.[57] This glaze is a colorless glass powder, producing a smooth, glossy finish.[57] However, at the time of insertion, restorations are often adjusted by a clinician with a dental handpiece and polishing burs in order to recontour the prosthesis or modify the occluding surface. Polished according the manufacturer's recommended protocol, this adjustment leaves the restoration with an unglazed, highly-polished finish. After clinical insertion, restorations are subject to mechanical abrasion from the patient as well. Both toothbrushing and functional wear of a restoration abrade a material's surface, further removing the glaze that once protected the restoration's surface. Abrasion on ceramic dental materials and

it's resulting roughness has been previously investigated. An unmodified glazed ceramic has a reported roughness (Ra) of 0.37-1.03 μm, while a ceramic polished by fine dental polishing rubbers has a corresponding reported roughness (Ra) of 1.63-2.42 μm.[72] As outlined by Yuan et al's research, mechanical abrasion alters the surface roughness of a material.[73] Upon toothbrush abrasion, Yuan et al's research showed that the mean roughness of the lithium disilicate surface increases while the mean roughness of the zirconia surface becomes smoother with tooth brush abrasion.[73] For lithium disilicate, this resulting increase in roughness renders a surface more susceptible to staining agents.[56]

After insertion, a dental restoration is often subjected to a plethora of staining agents, including medications, red wine, coffee, tea, and cigarette smoke. Staining agents can render the appearance of a restoration via color change in different ways. When plaque and external stain accumulates on the external surface of a restoration, a biofilm is produced. Depending on the roughness and penetrability of the surface, this biofilm and staining can permeate the porosities of a surface and sub-surface, leading to permanent changes in the appearance and color of a restoration.[43] In addition, physical changes and degradation of the structure of a material can lead to inherent internal color change.[38-41]

2.5 Color Stainability of Traditional Dental Materials

Exposure to different agents can lead to staining of the external film on materials. Staining agents can alter the surface roughness of materials as well, increasing its stainability. Ayaz et al noted that when exposed to staining agents of cigarette smoke and denture cleaner, acrylic denture teeth displayed higher color difference (ΔE) values than acrylic resin denture teeth, which both showed higher ΔE values than porcelain

denture teeth.[42] The authors also found that materials exposed to cigarette smoke displayed larger increased surface roughness as well as ΔE values than materials exposed to cigarette smoke with denture cleaning solution or denture cleaning solution alone.[42]

Belli et al studied color stability of different esthetic laminate materials exposed to different staining agents as well. In this study, indirect composite, direct composite, and feldspathic porcelain were exposed to Turkish coffee, tea, cigarette smoke, and water. It was found that staining ability was greatest with cigarette smoke, followed by Turkish coffee, tea, and water respectively.[52] Color stability was found to be greatest in feldspathic porcelain, followed by indirect composite and direct composite respectively.[52]

In another study, Patil et al investigated the staining of acrylic resin denture teeth when exposed to cigarette smoke through a negative pressure smoke chamber. Based on their studies, the authors also noted that exposure to cigarette smoke by acrylic resin teeth led to significant color change in the material.[46] These results were consistent with other similar studies.

Conducted by Lauvahutanon et al, a study investigated the discoloration of CAD/CAM block materials after immersion in coffee. In this study, different CAD/CAM restorative blocks were immersed in coffee for one month to reveal that ceramic materials exhibited the greatest color stability over time, followed by CAD/CAM composite blocks. Conventional restorative composites exhibited the greatest color staining. Following exposure to the staining agents, polishing with prophylaxis paste decreased the staining of the CAD/CAM materials as well as the conventional composite materials.[53] It was also found that the staining was primarily extrinsic, as opposed to an intrinsic color change related to the internal matrix of the composite.[53]

In a study conducted by Bazzi et al, the stainability of enamel by cigarette smoke and coffee was investigated, as well as the ability to remove the stain by tooth-brushing. In

this study, similar ΔE values were obtained when exposing the enamel to the two different staining agents: coffee immersion for 72 hours and cigarette smoke for 10 minute intervals at 4 separate exposures.[54] After this, the tooth brushing resulted in higher removal of the staining in the cigarette smoke-exposed enamel compared to the coffee-stained enamel.[54]

Atay et al investigated the stainability of feldspathic porcelain when immersed in different staining agents over time periods of 2 days, 7 days, and 30 days in wine, cola, and coffee. This study also compared the staining relative to the surface treatment of the porcelain: naturalglaze, ion-exchange, overglaze, and polished. The results of this study showed a direct relationship between the time immersed in a staining agent and the amount of color change for polished feldspathic porcelain.[55] The staining agent used did not contribute to significant differences in stainability, however the polished surface treatment was associated with significantly more staining than glazed porcelain surfaces.[55]

In a similar study, Motro et al investigated the stainability and surface texture of ceramics. In this study, the investigators studied the surface roughness of ceramics after adjustment with diamond burs, polishing with different polishing systems, and glazed ceramics. They reported highest roughness values in the diamond-cut ceramics, followed by polished ceramics, and the smoothest surface texture with glazed ceramic. Stainability followed the same order, with glazed ceramics exhibiting the least amount of stainability.[56] It was reported that a positive significant relationship of 65.6% was found between the roughness (Ra) and the color change (ΔE) values of the materials.[56]

Alandia-Roman et al investigated the effect of cigarette smoke staining to composite materials. Hybrid, nano, and micro-hybrid composite materials were the subjects of the study. In this study, the cigarette smoke exposure was completed in 10 minute intervals of 20 cigarettes per sample. After exposure, a tooth brushing apparatus was also constructed and used to remove excess cigarette smoke residue on the surface.

The results of this study looked at comparisons amongst surface roughness, different changes in the L*, a*, and b* values, as well as ΔE values. In the study, polished composite materials exhibited mean roughness values (Ra) of .013-.068, whereas unpolished composite was associated with mean roughness values (Ra) of .079-.266. ΔE values were investigated, ranging from 1.79-3.39, with significantly lower values for the polished, smoother composites compared to the unpolished, rougher composite surfaces.[38] Finally, as outlined in the literature, changes in the luminosity (L*) of materials is most easily detected by the human eye, as human eyes contain much higher numbers of rods, which are the cells responsible for detecting lightness or greyness, than cones, which are responsible for detecting hues. Therefore, the L* values of color analyses are of the upmost importance in dentistry and esthetics. In this study, significant L* value reductions (darkening) within the materials exposed to cigarette smoke were noted.[38] This further substantiates the unesthetic effects and staining that cigarette smoke exposure causes to dental materials.

3. METHODOLOGY

3.1 Study Design

In this study, 100 discs (each 2mm thick) are prepared of 5 different CAD/CAM surface-finish (lithium disilicate glazed, lithium disilicate polished, zirconia glazed, zirconia polished and acrylate polymer). Each of the 5 different sample groups produces 20 discs. Each of the 5 sample groups are further blindly halved into a control group and an experiemental group, each with a sample size of 10 specimens. The specimens are numbered for consistency throughout the study. The specimens are glazed and polished according to the manufacturer's recommendations.

After sample preparation, baseline color measurements are performed using a spectrophotomer for all specimens.

The test samples are subjected to the following smoking conditions of a negative pressure custom-made smoking chamber. The specimens were exposed to the smoke for 3 seconds per inhalation. Ambient air was then inhaled and replaces the smoke in the chamber. Specimens were subjected to the smoking of 1 pack of Marlboro cigarettes per day for a total of 10 days. In the intervals between exposures, the specimens were stored in artificial saliva (1.5 mM Ca, 0.9 mM Pi, 150 mM KCL, 0.05 lg F/mL, 0.1 M Tris buffer [pH=7.0]) at 37ºC to simulate clinical conditions when they were not being subjected to the smoking conditions. The control specimens are stored in a separate saliva solution composed in the same manner for 10 days. All saliva solutions are reconstituted daily.

After exposure, spectroradometry is performed in the same way as baseline color measurement to obtain post-ageing and post-exposure color measurements. Changes in color are measured between each sample's readings using the L*a*b values to quantitatively analyze the shade difference of each treatment group.

Following post-exposure and post-ageing color measurement, a constant-pressure lateroscursive brushing apparatus is used to remove excess smoke residue that has accumulated on the specimen surfaces. Brushing of the specimens includes 10 forward-backward movements of the table on the surveying platform with constant pressure of the tooth brush bristles against the specimen, with water available around the specimen up to the level of the specimen surface.

Samples are then subjected to spectroradiometric measurement for a final time to obtain post-brushing color measurements. Changes in color are measured between each sample's three readings using the L*a*b values to quantitatively analyze the shade difference of each treatment group.

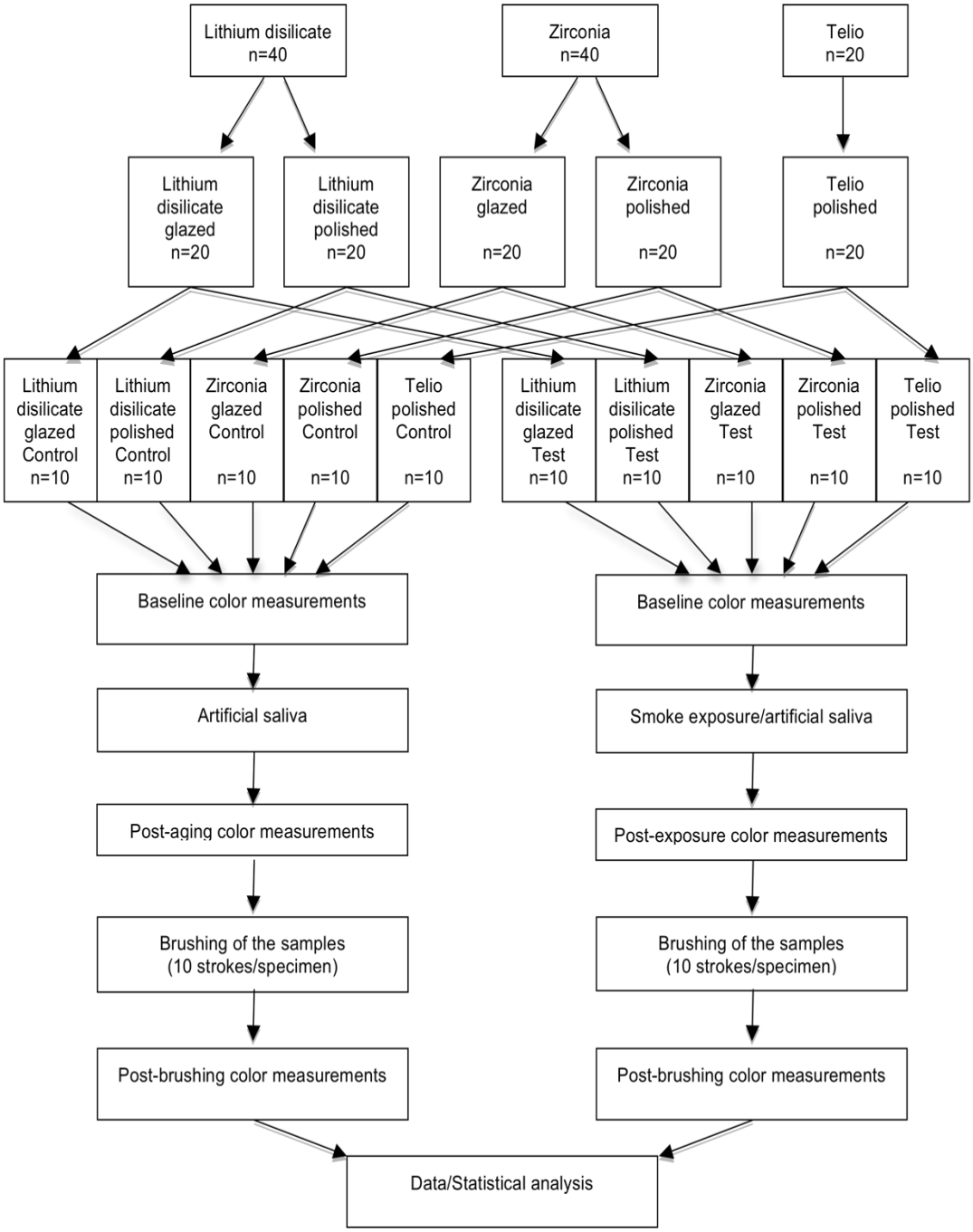

Figure 1. Study Design

3.2 Materials and Methods

Specimen Preparation

For the specimen preparation, three CAD/CAM-available restorative materials investigated in this study: Ivoclar Vivadent's lithium disilicate CAD (e.max CAD), Telio CAD, and Wieland Zenostar zirconia. From the raw restorative pucks and ingots, 40 e.max CAD discs, 40 zirconia discs, and 20 Telio discs were prepared using a IsoMet 1000 Precision Cutter (Buehler). Each disc was cut at a setting of 2mm thickness, and the discs were cut with the saw under water and at a speed of 200 rpm.

After sectioning, the surface of the discs were left with surface irregularities. In order to create a surface that would most replicate a dental restoration, which has been reported to have a surface roughness of less than 2 micrometers, the discs were then smoothed with fine polishing paper under water. This eliminated any surface irregularities that were left after the initial cutting. The resulting thickness of the discs remained at 1.8 +/- .1mm, measured with calipers.

After this preparation, the blue stage e.max CAD specimens were steam-cleaned and dried with paper towels before glazing and crystallizing. A thin layer (2 brush strokes) of e.max crystallize/glaze (Ivoclar Vivadent) was applied to one side of each e.max CAD specimen. Object fix (Ivoclar Vivadent) was utilized to place the specimens onto a temperature stable stand to stabilize the specimens while crystallizing in the oven. Due to the size of the aperture of the oven, 4 specimens were crystallized per firing cycle. An Ivoclar Vivadent Programat CS2 oven was used to crystallize the e.max CAD specimens on P1 crystallizing cycle settings.

The green stage zirconia specimens were sintered and glazed according to the following manufacturer recommendations from Dentsply Sirona. These settings included

a start time at room temperature. The heating velocity was set at a rate of 12°C/minute to the final holding temperature of 1540°C for 120 minutes. Following, the temperature was decreased at a rate of 10°C/minute to room temperature.

After the aforementioned second stage specimen preparation, they were assorted into their respective groups. At this point, the specimens were blindly and randomly assigned to the following groups:

E.max CAD A (10 specimens) → glazed, control

E.max CAD B (10 specimens) → glazed, experimental

E.max CAD C (10 specimens) → polished, control

E.max CAD D (10 specimens) → polished, experimental

Zirconia A (10 specimens) → glazed, control

Zirconia B (10 specimens) → glazed, experimental

Zirconia C (10 specimens) → polished, control

Zirconia D (10 specimens) → polished, experimental

Telio A (10 specimens) → polished, control

Telio B (10 specimens) → polished, experimental

After group assignment, each specimen was designated a unique double-digit number to maintain record of the data associated with each specimen throughout the study. The numbers were then recorded in Microsoft Excel.

Finally, groups e.max CAD C, e.max CAD D, Zirconia C, Zirconia D, Telio A, Telio B were polished to simulate the clinical adjustment and polishing of a restoration. In order to achieve this, each specimen was lightly abraded with a fine diamond bur with electric handpiece at 10,000 rpm under water irrigation. Subsequently, the ceramic specimens (e.max and zirconia) were polished with the Optrafine F, followed by Optrafine P, and finally Optrafine HP with a contra-angle handpiece at 10,000 rpm. The

Optrafine F and P polishing was completed under water irrigation; however the Optrafine HP polishing was utilized with diamond polishing paste, as instructed within Ivoclar Vivadent's protocol. In contrast, the Telio PMMA specimens were polished with the Optrapol under water irrigation, at a speed of 10,000 rpm, as instructed in their protocol (Ivoclar Vivadent). After this point, the preparation of all specimens was completed.

Sample Testing and Color Measurement

Baseline color measurements were performed in Alvin Wee's Craniofacial Color Research Laboratory at Creighton University, using a spectroradiometer. The spectral reflectance of each sample was measured with a spectroradiometer from 380 nm to 780 nm wavelengths at 5 nm interval with an optical configuration of 45 degree illumination and 0 degree observer angle. The spectral data for each specimen was then recorded in Microsoft Excel and converted to CIELAB values for a 2 degree observer with D65 illumination, which was also recorded in Microsoft Excel.

Upon completion of initial spectral measurements, all specimens were taken to Brazil to undergo their respective experimental testing. Our collaborator on this study, Valentim Barao used a negative pressure, isolated cigarette smoke exposure chamber for this study. The chamber was constructed from specifications that were outlined in a previously published related study by Alandia-Roman (Effect of cigarette smoke on color stability and surface roughness of dental composites. *Alandia-Roman CC, Cruvinel DR, Sousa AB, Pires-de-Souza FC, Panzeri H J Dent. 2013 Aug; 41 Suppl 3():e73-9)*. The experiment samples (e.max CAD B and D, zirconia B and D, Telio B) were be subjected to the following smoking conditions: The negative pressure chamber works as an inhalation starts and conducts smoke through glass cannulas aiming to allow it to circulate and deposit the chemical products on the specimens.[6,10] Cycles of smoking are

scheduled on time intervals, replicating the typical smoking behavior of a smoker. The specimens were exposed to the smoke for 3 seconds per inhalation. Ambient air was then inhaled and replaces the smoke in the chamber. Specimens were subjected to the smoking of 1 pack of Marlboro cigarettes per day for a total of 10 days. In the intervals between exposures, the specimens were stored in artificial saliva (1.5 mM Ca, 0.9 mM Pi, 150 mM KCL, 0.05 lg F/mL, 0.1 M Tris buffer [pH=7.0]) at 37ºC to simulate clinical conditions when they were not being subjected to the smoking conditions. Every 24 hours, the specimens were washed with distilled water and resubmerged in fresh artificial saliva solution to prevent sedimentation. The control specimens were stored in artificial saliva solutions of the same composition for 10 days without removal.

After the 10 days of exposure, color measurements were performed in the same way as the baseline color measurements at Creighton University, and the data was recorded in Microsoft Excel.

Due to the irregularities of residue that remained on the specimens' surfaces after exposure, the specimens were then brushed to remove any gross residue amounts that had collected. The objective of the study was to measure the staining of the material rather than the spectroradiometry of residue accumulation on the surface, and therefore it was decided that the most appropriate measure of stain would be after removal of these accumulations. A constant-pressure, lateroscursive tooth brushing apparatus was constructed, from specifications outlined in a previously published related study.[38] This apparatus was constructed from a dental surveyor, with the addition of an attached toothbrush head to the mandrel and a PMMA well for specimen placement on the surveying table. Brushing of the specimens included 10 forward-backward movements of the table on the surveying platform with constant pressure of the tooth brush bristles against the specimen, with water available around the specimen up to the level of the

specimen surface, but not submerging the specimen under water. This is to cleanse the specimen and bristles throughout the brushing between strokes.

After brushing, final post-brushing spectroradiometry measurements were made, and the data was recorded in Microsoft Excel. The color change (ΔE) was calculated before and after the intervention performed for all specimens. Change in color was later calculated between each specimen's two readings using the L*a*b values to quantitatively analyze the shade difference of each treatment group. Color differences were calculated using the ΔE formula indicated below. Statistical analysis was performed using independent t-test between control and experimental group within each surface finish treatment for each material, at 95% confidence level. The independent variable includes the smoke exposure whereas the dependent variable is color change before and after treatment.

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

Image 1. Materials in boxes

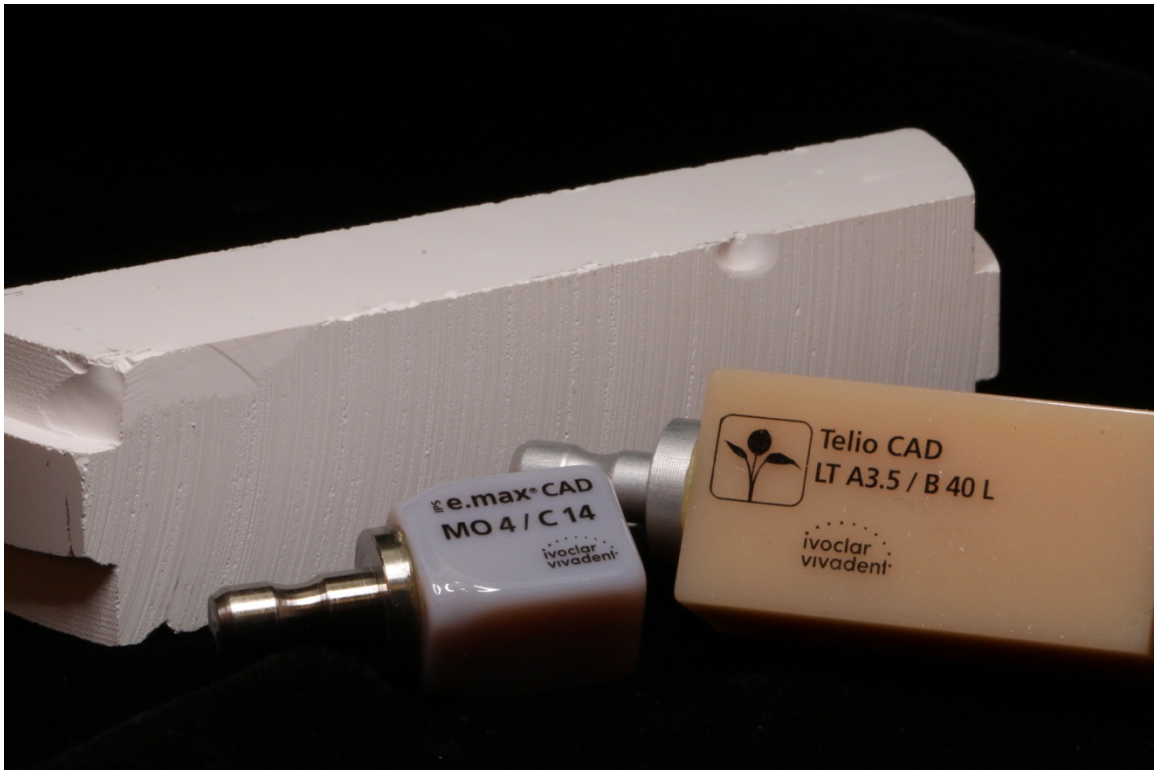

Image 2. Materials in raw

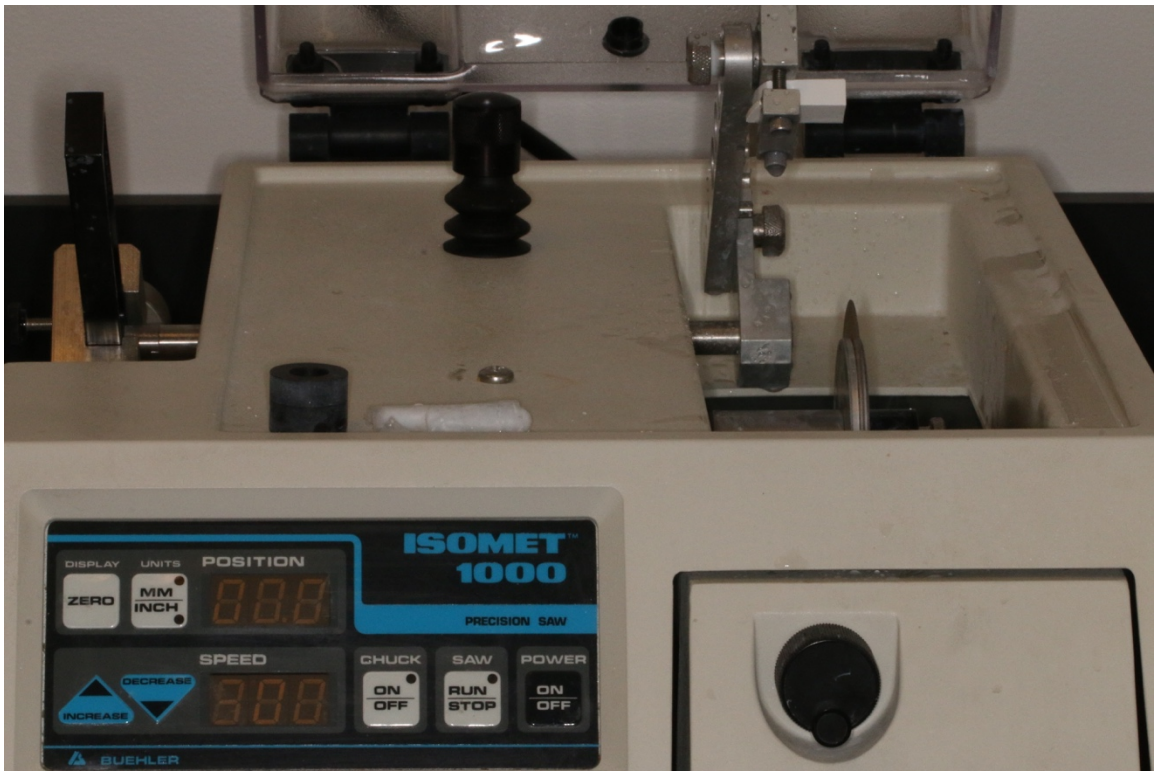

Image 3. Isomet 1000

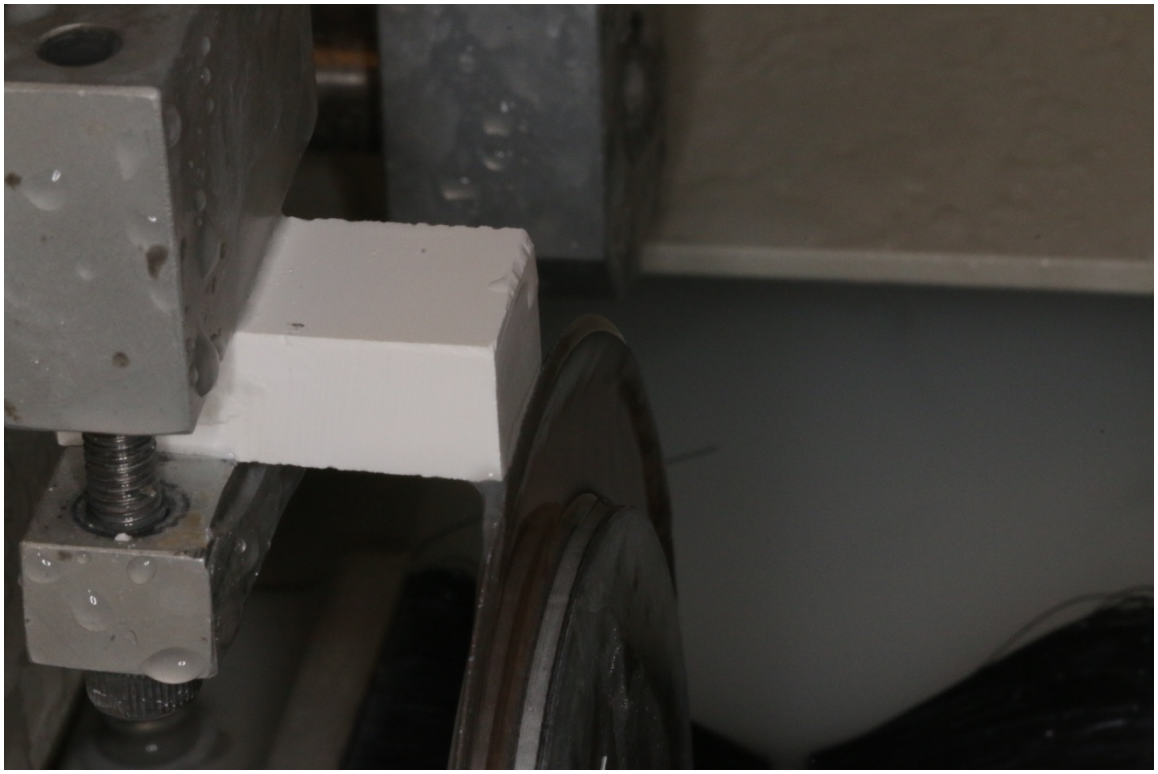

Image 4. Cutting of the discs

Image 5. Cut samples

Image 6. Sanding machine

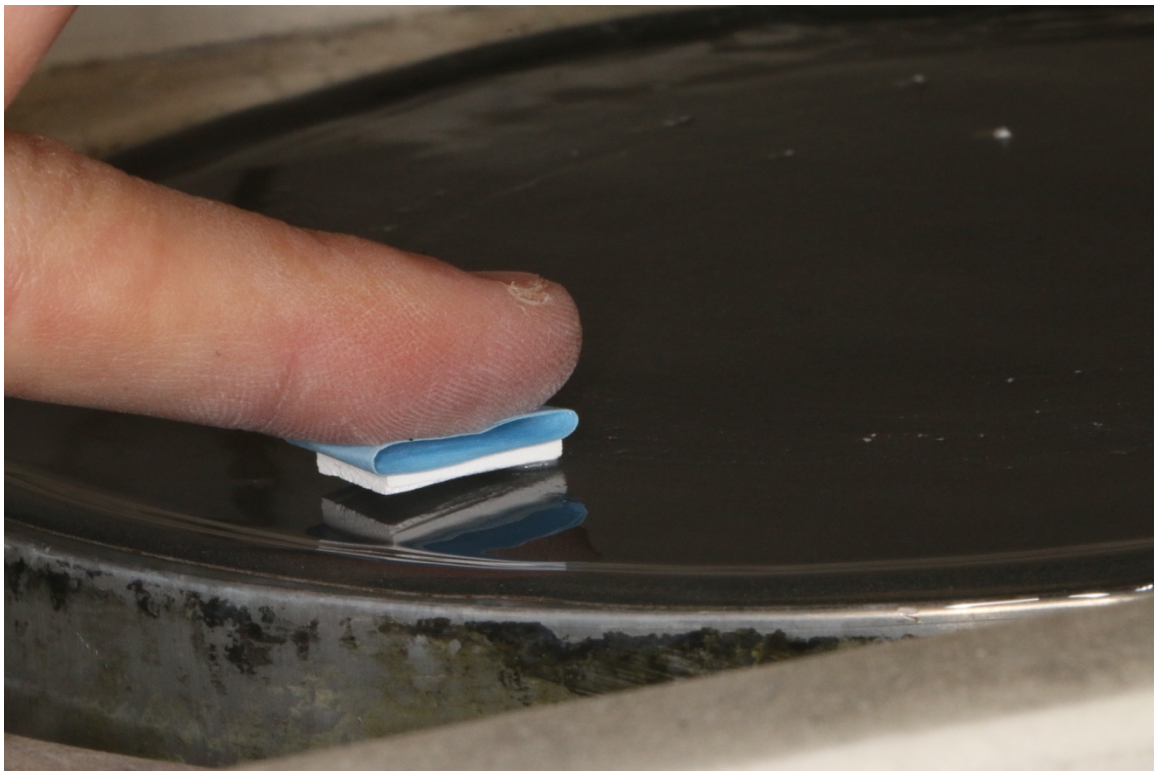

Image 7. Sanding of samples

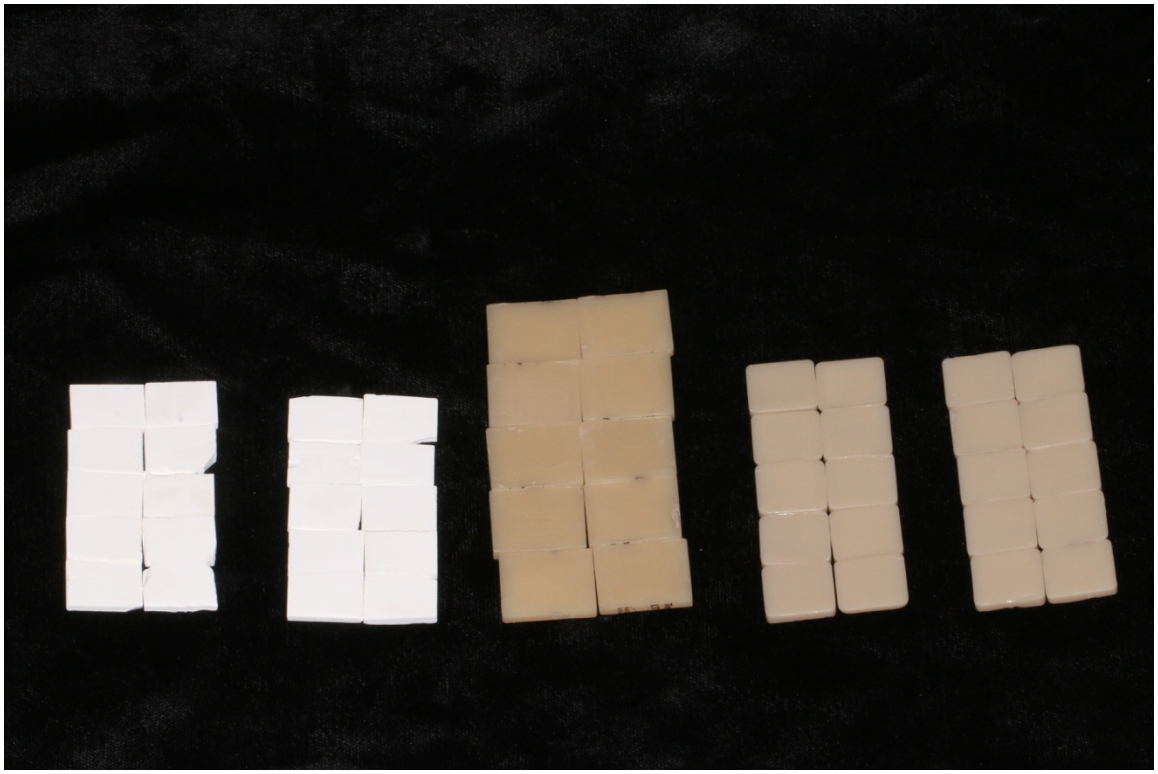

Image 8. Smoothed discs

Image 9. Crystallize/Glaze and object fix

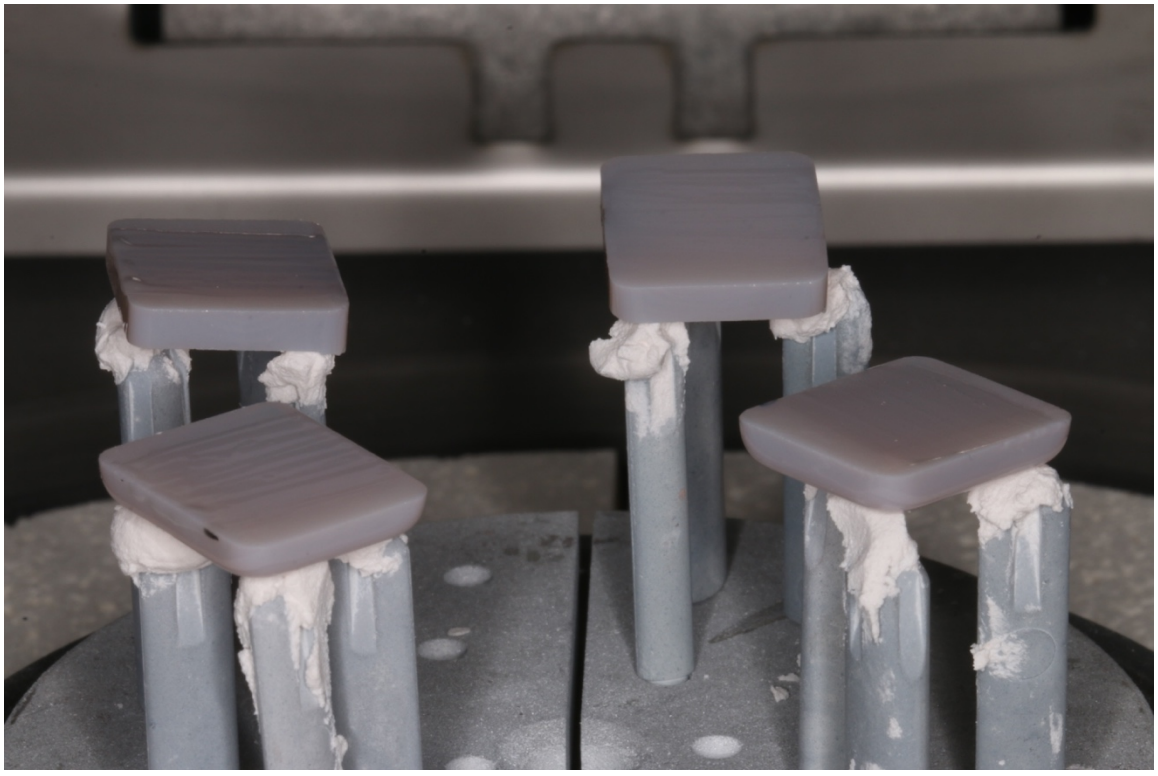

Image 10. C/G e.max specimens in place

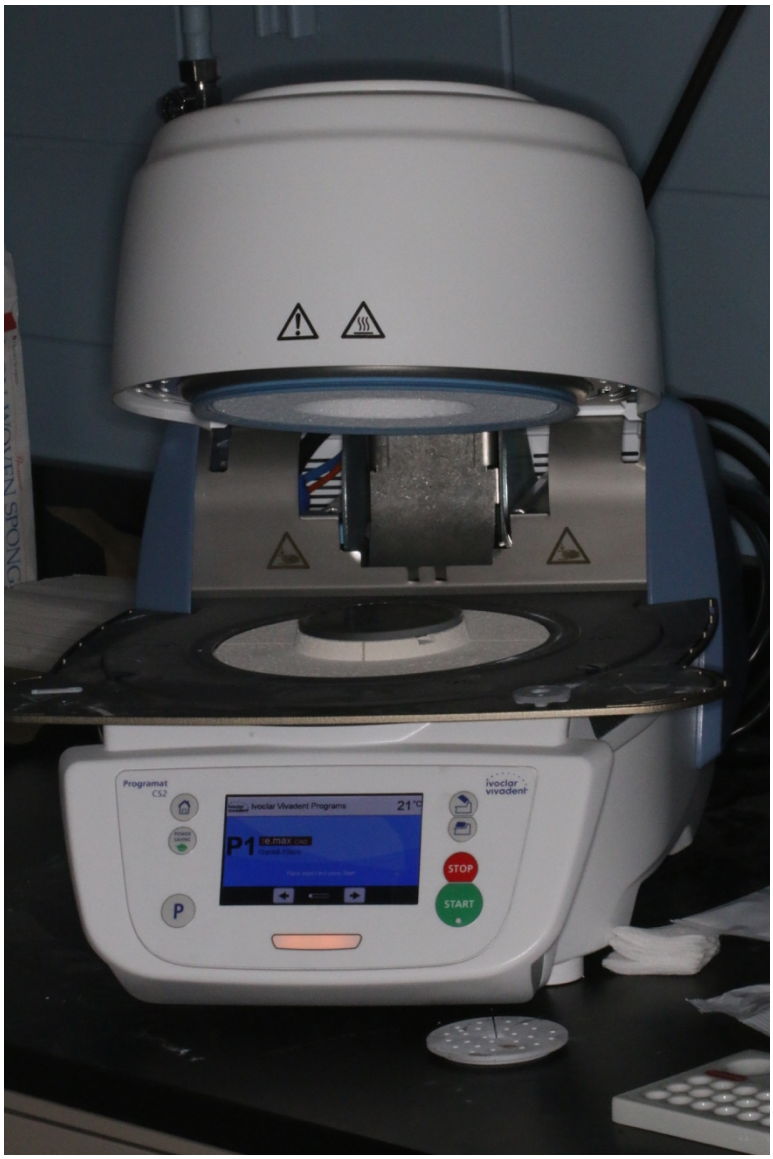

Image 11. Ivoclar Vivadent Programat CS2

Image 12. Crystallized/Glazed e.max specimens

Image 13. Sintered/Glazed Zirconia specimens

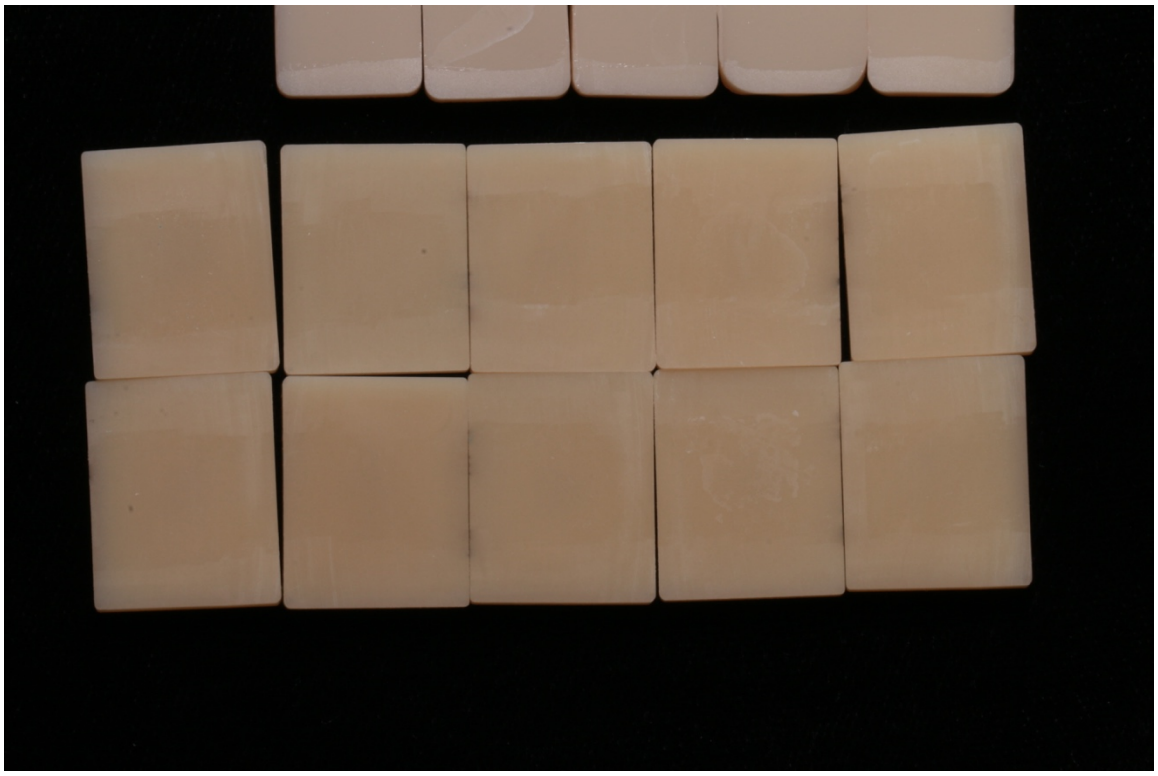

Image 14. Prepared Telio specimens

Image 15. Optrafine/Optrapol Polishing kits

Image 16. Final polished samples

Image 17. Final glazed samples

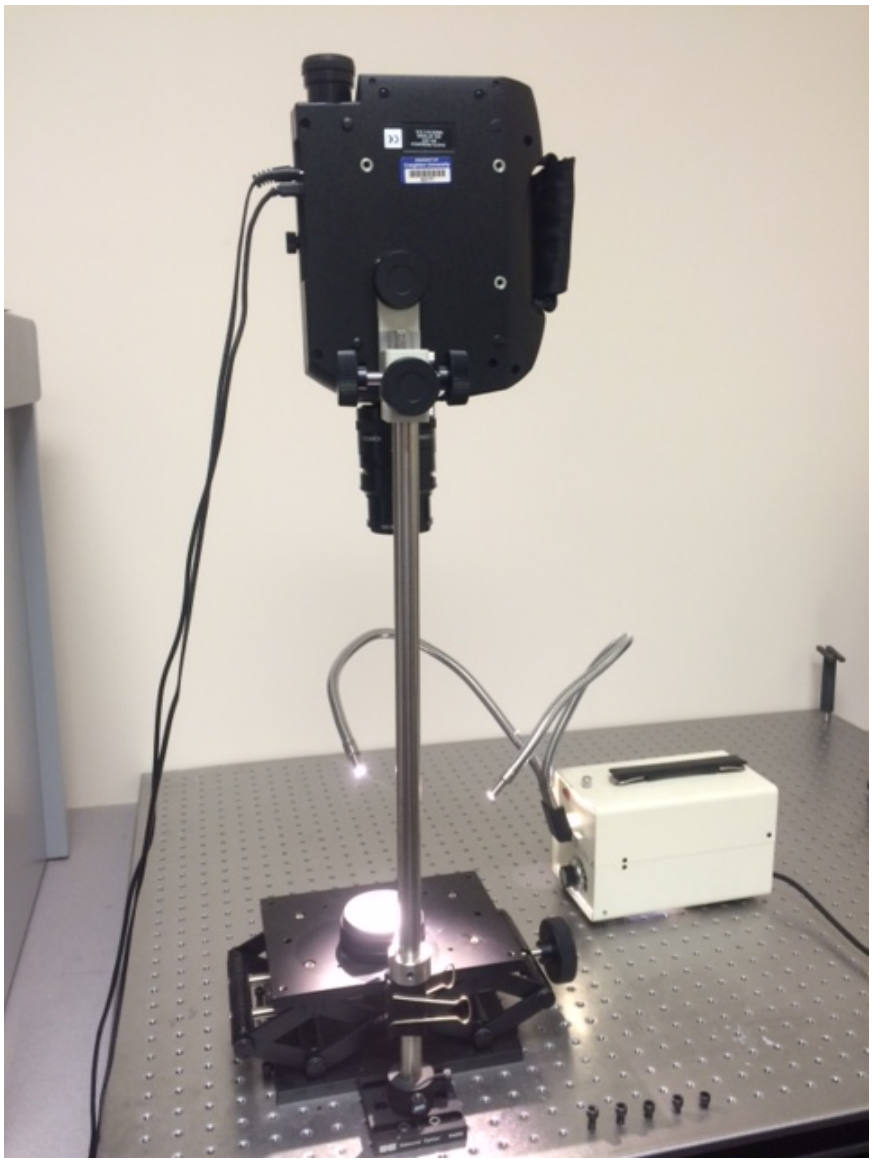

Image 18. Spectroradiometer

Image 19. Smoke chamber

Image 20. Post smoke-exposure samples

Image 21. Post smoke-exposure and ageing samples

3.3 Statistical Analysis

Data were recorded Microsoft Excel spreadsheet for reporting and analysis (Microsoft Excel, Redmond, Washington, USA). Statistical analysis was completed for the data using statistical software (SPSS v.20, Armonk, NY, USA).

1. Lithium Dilicate
    a. 2-way and 3-way repeated ANOVA were used with 3 independent variables: surface (glazed and polished), time (baseline, after exposure/ageing, after brushing), and exposure type (smoking or ageing).
    b. Post-hoc Bonferroni tests were used for all statistically-significant interactions and isolated factors
2. Zirconia
    a. 2-way and 3-way repeated ANOVA were used with 3 independent variables: surface (glazed and polished), time (baseline, after exposure/ageing, after brushing), and exposure type (smoking or ageing).
    b. Post-hoc Bonferroni tests were used for all interactions and isolated factors that were found statistically-significant via ANOVA
3. Telio
    a. 2-way repeated ANOVA were used with 2 independent variables: time (baseline, after exposure/ageing, after brushing) and exposure type (smoking or ageing).
    b. Post-hoc Bonferroni tests were used for all interactions and isolated factors that were found statistically-significant via ANOVA

4. DATA AND RESULTS

See tables 1-31 for details of reported data.

All spectrophotometry was conducted from 380 nm to 780 nm wavelengths at 5 nm interval with an optical configuration of 45 degree illumination and 0 degree observer angle. The spectral data was converted to CIELAB values for a 2 degree observer with D65 illumination. After initial preparation, all samples were sent for baseline RFA spectral analysis and data collection. Initial L*, a*, and b* values were measured and recorded from the baseline measurements for both test and control samples of e.max (glazed), e.max (polished), zirconia (glazed), zirconia (polished), and Telio. These values can be seen in tables 1-20 under "baseline."

After being subjected to the cigarette smoke environment (experimental samples) and the ageing environment (control samples), "after smoking" and "after ageing" spectral measurements and L*, a*, and b* values were recorded for the experimental samples and control samples, respectively. This data is seen in tables 1-10 and 21-30 under "after smoking" and "after ageing,"

Finally, all samples were subjected to brushing to remove excess gross residue remaining on the specimens' surface. Again, all samples were then returned for "after brushing" spectral data collection and recording. All "after brushing" L*, a*, and b* values can be found in tables 11-30.

From the recording of these spectral data, ΔE, ΔL^*, Δa^*, and Δb^* values for the individual specimens can be calculated to reveal changes in color in the samples throughout testing.

For the color change seen in the experimental samples between baseline and after smoking, mean ΔE values ranged from 12.8 to 19.2. The highest mean ΔE value was seen in the e.max (polished) sample with a value of 19.2 +/- 4.8. In order of descending mean ΔE values, e.max (glazed), zirconia (glazed), zirconia (polished) were 18.8 +/- 5.8, 18.5 +/- 3.8, and 16.8 +/- 2.6 respectively. The lowest mean ΔE was found in the Telio sample, with a mean ΔE value of 12.8 +/- 5.2.

These experimental values can be compared against the corresponding control samples, which had mean ΔE values ranging from 1.3 - 5.0. Comparing the ΔE values between the experimental and control samples, all p values were noted to be <0.001.

The brushing of the specimens led to the removal of excess gross smoke residue that remained on the surfaces. In measuring the color change between the post-smoking measurements and the post-brushing measurements, mean ΔE values ranged from 13.7 to 20.3. The polished e.max sample had the largest mean ΔE value of 20.3 +/- 4.4, followed by glazed e.max, which had a mean ΔE value of 18.6 +/- 6.2. The glazed zirconia and polished zirconia had mean ΔE values of 16.5 +/- 6.3 and 13.7 +/- 3.9 respectively. The telio sample was found to show a mean ΔE value of 14.9 +/- 5.0.

These experimental values can be compared against the corresponding control samples, which had mean ΔE values ranging from 0.7 to 2.9. Comparing the ΔE values between the experimental and control samples, all p values were noted to be <0.001.

The final color change data that was quantitatively analyzed was the overall color change from the baseline measurements to the post-brushing measurements. These mean ΔE values ranged from 2.5 to 9.6. The polished zirconia sample demonstrated the largest mean ΔE value, 9.6 +/- 1.8. Telio and glazed zirconia showed the next largest color change with mean ΔE values of 8.7 +/- 2.4 and 7.9 +/- 3.2 respectively. Finally, the

polished e.max and glazed e.max samples had the smallest overall color change, with mean ΔE values of 5.3 +/- 3.8 and 2.5 +/- 0.4 respectively.

These experimental values can be compared against the corresponding control samples, which had mean ΔE values ranging from 0.7 to 4.3. Comparing the ΔE values between the experimental and control samples, p values were noted to be <0.001 for the glazed e.max, polished zirconia, and telio samples. In comparing the experimental and control glazed zirconia samples, the p value was found to be 0.002. In comparing the experimental and control polished e.max samples, the p value was found to be 0.01.

4.1 STATISTICAL ANALYSES OF DATA

See table 31 for details of reported data and statistical analyses.

Litihium disilicate (e.max):

a. Based on the repeated 2-way ANOVA, the time ($p<0.001$), smoking ($p<0.001$) and the interaction between time and smoking ($p<0.001$) significantly affected the color difference of lithium disilicate. The surface finish ($p=0.184$) and the interactions between surface finish and smoking ($p=0.371$), time and surface finishing ($p=0.568$), and interaction among time, surface finishing and smoking ($p=0.721$) were not statistically significant.

b. Posthoc: Effect of smoking factor: Smoking statistically promoted color alteration of lithium disilicate material independent of the surface finishing ($p<0.001$).

c. Posthoc: Effect of time: All periods of evaluation induced color alteration where the period after smoking; and after smoking + brushing had the highest color alteration ($p<0.001$) but they were similar between them ($p=0.832$).

d. Posthoc: Effect of time*smoking: Smoked samples had higher color alteration than samples immersed just in saliva (control) ($p<0.001$) for all periods of evaluation. For the smoked samples, all periods of evaluation induced color alteration where the period after smoking; and after smoking + brushing had the highest color alteration and the period brushing the lowest one ($p<0.001$). For samples that were not smoked but immersed in saliva, all periods of evaluation had similar color alteration ($p>0.05$).

Zirconia:

a. Based on the repeated 2-way ANOVA, the time ($p<0.001$), smoking ($p<0.001$) and the interactions between time*surface finishing ($p=0.040$) and time*smoking ($p<0.001$) significantly affected the color difference of ZR. The surface finish ($p=0.472$) and interactions between surface finish*smoking ($p=0.429$) and time*surface finishing*smoking ($p=0.296$) were not statistically significant.

b. Effect of time*surface finishing: For all periods of evaluation, glazed and polished samples had similar color alteration ($p=0.272$ after smoking; $p=0.066$ after brushing; $p=0.170$ after smoking+brushing). For both surface finishing conditions (glazed and polished), all periods of evaluation promoted color alteration where after smoking samples had the highest color alteration ($p<0.001$), and after brushing the lowest one ($p<0.001$).

c. Effect of smoking*time: Smoked samples had higher color alteration than samples immersed just in saliva (control) ($p<0.001$) for all periods of evaluation. For the smoked samples, all periods of evaluation induced color alteration where the period after

smoking; and after smoking + brushing had the highest color alteration and the period brushing the lowest one ($p<0.001$). For samples that were not smoked but immersed in saliva, all periods of evaluation had similar color alteration ($p>0.05$), excepted after smoking vs after smoking+brushing ($p<0.001$).

Telio:

a. Based on the repeated 2-way ANOVA, time ($p=0.011$), smoking ($p<0.001$) and the interaction between time*smoking ($p=0.002$) significantly affected the color differences of telio.

b. Effect of smoking*time: Smoked samples had higher color alteration than samples immersed just in saliva (control) ($p<0.001$) for all periods of evaluation. For the smoked samples, all periods of evaluation induced color alteration where the period after smoking; and after smoking + brushing had the highest color alteration and the period brushing the lowest one ($p<0.05$). For samples that were not smoked but immersed in saliva, all periods of evaluation had similar color alteration ($p>0.05$), excepted after smoking vs after smoking+brushing ($p=0.002$).

5. DISCUSSION

5.1 Interpretation of the Current Results

Analysis of the recorded data and results allowed for conclusions to be drawn regarding the color stability and cigarette smoke stainability of the different restorative CAD/CAM materials. To review the goals of the study, the following specific aims were previously outlined:

1: Investigation of the color stainability of CAD Lithium Disilicate (Ivoclar Vivadent e.max), monolithic CAD zirconia, and CAD acrylate polymer PMMA (Telio) when exposed to cigarette smoke.

2: Investigation and comparison of the color stainability of CAD Lithium Disilicate (Ivoclar Vivadent e.max) in both its polished and glazed state when exposed to cigarette smoke.

3: Investigation and comparison of the color stainability of monolithic CAD zirconia (Ivoclar Vivadent zenostar zirconia) in both its polished and glazed state when exposed to cigarette smoke.

Although the properties of color stability and stainability of the different materials are investigated, due to differences in structural and chemical composition of materials, it is important to note that direct comparison of these properties amongst the different materials will not be drawn.

From the data and results, we see a strong color change in the material from baseline to post-smoke exposure. After exposure of the samples to the cigarette smoke in the chamber, large collections of cigarette smoke residue were noted on the surfaces of

the samples, leading to high reported average ΔE values between 12.8 and 19.2. This high ΔE value is not a true measurement of the internal staining of the material, but rather a measurement of the staining and the gross residue on the surface. From the tooth brushing, it is seen that ΔE values from 13.7 to 20.3 were achieved from the post-smoking measurements to the post-brushing measurements. Therefore, the tooth brushing allowed removal of excess residue on the surface to provide the final specimens to be measured a more true staining of the material.

From the ΔE values calculated between the pre-smoke exposure and post-smoke exposure/post-brushing, we can evaluate the color stability and stainability of the different materials. Because the different materials had differing initial L*a*b* values, it is important to evaluate the color change in the specimens as the ΔE values, rather than the final post-smoke exposure L*a*b* values. As we noted from our results, all samples exhibited greater color change after exposure to the cigarette smoke compared to the control samples that were only subjected to ageing. For the zirconia samples, regarding the interaction of smoking and time, smoked samples had higher color alteration than samples immersed just in saliva (control) ($p<0.001$) for all periods of evaluation. For the smoked samples, all periods of evaluation induced color alteration where the period after smoking; and after smoking + brushing had the highest color alteration and the period brushing the lowest one ($p<0.001$). For samples that were not smoked but immersed in saliva, all periods of evaluation had similar color alteration ($p>0.05$), excepted after smoking vs after smoking+brushing ($p<0.001$). For the lithium disilicate samples, the interaction between time and smoking color change showed statistical significance. Looking at the effect of smoking behavior, smoking statistically promoted color alteration of lithium disilicate material independent of the surface finishing ($p<0.001$).

All periods of evaluation induced color alteration, where the period after smoking; and after smoking + brushing had the highest color alteration ($p<0.001$) but they were similar between them ($p=0.832$). For the Telio PMMA samples, Based on the repeated 1-way ANOVA, time ($p=0.011$), smoking ($p<0.001$) and the interaction between time*smoking ($p=0.002$) significantly affected the color differences of Telio. For the smoked samples, all periods of evaluation induced color alteration for the period after smoking; and after smoking + brushing had the highest color alteration and the period after brushing the lowest one ($p<0.05$). From this, we reject our null hypothesis that the comparison of the ΔE values of the e.max glazed, e.max polished, zirconia glazed, zirconia polished, and Telio will not display a significant difference between the control specimens and the test specimens.

When evaluating the stainability of the materials, it is important to assess the stainability in relation to the finishing of the material. For the zirconia and the e.max materials, we investigated the stainability of both the glazed and the polished finishing. When analyzing the polished vs glazed e.max data, based on a repeated 2-way ANOVA, we found the surface finish, color change, and time did not show statistical significance. Looking at the effect of smoking behavior, smoking statistically promoted color alteration of lithium disilicate material independent of the surface finishing ($p<0.001$). Regarding the effect of time, all periods of evaluation induced color alteration where the period after smoking; and after smoking + brushing had the highest color alteration ($p<0.001$) but they were similar between them ($p=0.832$). Based on the repeated 2-way ANOVA, the time ($p<0.001$), smoking ($p<0.001$) and the interaction between time and smoking ($p<0.001$) significantly affected the color difference of lithium disilicate, indicating that exposure to cigarette smoke leads to greater staining of both polished and

glazed lithium disilicate. The surface finish ($p=0.184$) and the interactions between surface finish and smoking ($p=0.371$), time and surface finishing ($p=0.568$), and interaction among time, surface finishing and smoking ($p=0.721$) were not statistically significant.. Based on this, we accept our second null hypothesis that the comparison of staining (ΔE values) of the CAD lithium disilicate in its glazed and polished state will not display a significant difference.

Regarding the zirconia samples, we also investigated the stainability of the glazed and polished finish. When analyzing the polished vs glazed zirconia data, based on a repeated 2-way ANOVA, we found the surface finish, color change, and time did not show statistical significance. For both surface finishing conditions (glazed and polished), all periods of evaluation promoted color alteration where after smoking samples had the highest color alteration ($p<0.001$), and after brushing the lowest one ($p<0.001$). Based on the repeated 2-way ANOVA, the time ($p<0.001$), smoking ($p<0.001$) and the interactions between time*surface finishing ($p=0.040$) and time*smoking ($p<0.001$) significantly affected the color difference of ZR. The surface finish ($p=0.472$) and interactions between surface finish*color change ($p=0.429$) and time*surface finishing*color change ($p=0.296$) were not statistically significant. Regarding the effect of time and surface finish, for all periods of evaluation, glazed and polished samples had similar color alteration ($p=0.272$ after smoking; $p=0.066$ after brushing; $p=0.170$ after smoking+brushing). Based on this, we accept our third null hypothesis that the comparison of staining (ΔE values) of the monolithic CAD zirconia in its glazed and polished state will not display a significant difference.

5.2 Discrete Comparison of Results to Specific Values in the Literature

Although specific quantitative comparisons can not be drawn between our study's data and the data from other existing similar studies, the results and conclusions of our studies based on our data can be qualitatively compared to past studies. Based on our data and results, it is evident that all of the materials studied were susceptible to staining when exposed to cigarette smoke. This finding is consistent with previously reported conclusions from past studies investigating stainability of dental materials. Motro and Kursoglu et al have both reported a significant color change in ceramic when immersed in coffee.[56] Palla et al reported significant staining in e.max lithium disilicate when submerged in various liquids, such as tea, coffee, and wine.[74] Similarly, Santos reported significant color change noted upon immersion of lithium disilicate in beverages such as cola, orange juice, coffee, and wine.[75] Finally, Alandia-Roman's study on the effects of cigarette smoke on composites reported significant color change noted amongst all composites exposed to cigarette smoke.[38] Our study's findings are consistent with the reported literature concerning a noted susceptibility to staining amongst various dental materials.

Although we are not directly comparing quantitative color change between different materials in our study, we did analyze the color change against different surface finishes of the same material. Regarding both lithium disilicate and zirconia, no statistical significance was found comparing polished and glazed surfaces of each material. Studies have reported an increased surface roughness associated with polished finishing compared to glazed finish.[56,73, 76, 77] In the literature, the overall consensus on the correlation between roughness and stainability is inconclusive, yet favors a direct relationship between surface roughness and stainability when exposed to staining agents. Some studies, such as yuan 2017, found no statistically significant interaction between roughness and stainability. Our

data and findings are consistent with Yuan et al's research, noticing a greater color change with polished surfaces but lacking any statistical significance pertaining to a relationship between the surface finish of the samples and stainability.

5.3 Consideration of Structure-Property Relationships

A material's properties are determined by its chemical composition, structural configuration, and iatrogenic manipulation of the material. As concluded by past studies, the roughness of a material's surface, affected by the adjustment and polishing of a material, has a direct relationship with the stainability of a material. [56,73, 76, 77] Similarly, the material's internal chemical composition may also affect its color stability and stainability.

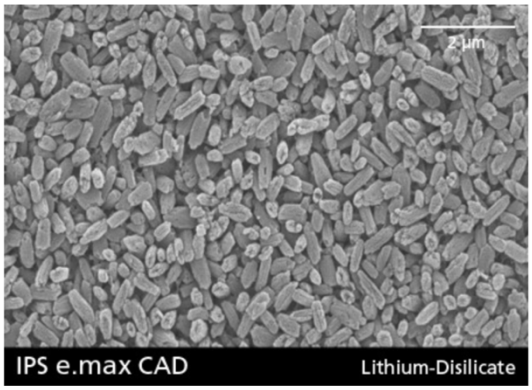

Image 21: IPS e.max CAD surface after etching with HF acid, fully crystallized. (SEM)[20]

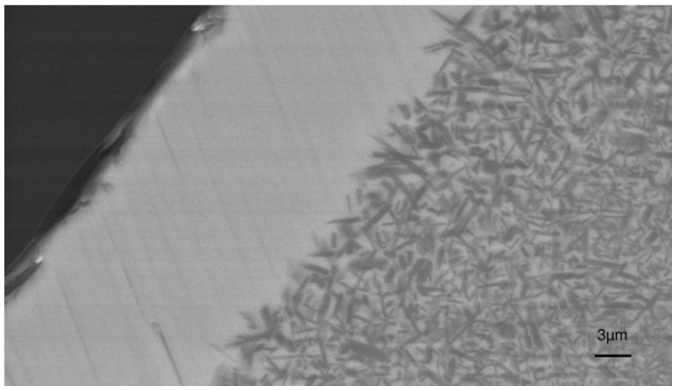

Image 22: cross section of IPS e.max CAD fully crystallized, with instant glaze applied and subsequently polished. (SEM)[20]

The chemical composition of e.max CAD includes a 70% lithium disilicate crystals embedded in a glassy matrix. As can be seen here in image 21 which was provided by Ivoclar Vivadent,[20] the internal crystal structure of e.max CAD is rather rough and

heterogenous at the scanning electron microscope level. When fabricated, this material is subjected to milling by diamond burs to obtain a restoration, as designed via CAD. This milling leads to a surface roughness characterized by the coarseness of the burs used for milling as well as the material's structural properties. Subsequently, glaze is applied to the restoration to provide a final material finish to the restoration. As can be seen in image 22, also provided by Ivoclar Vivadent,[20] the glaze applied creates a more homogenous, glassy surface on the material, covering the rough e.max CAD crystal structure.

Zirconia has a reported internal cubic and tetragonal structural lattice that is specific to zirconia material. Through SEM imagining, it is evident that zirconia possesses a relatively smooth surface (Image 23). Similar to e.max restoration fabrication, zirconia is subjected to milling via a diamond bur to achieve a restoration. The roughness of this restoration's material surface is characterized by the coarseness of the diamond bur used for milling as well as the material's structural properties. Subequently after sintering, a glaze is applied to achieve a restoration's final material surface.

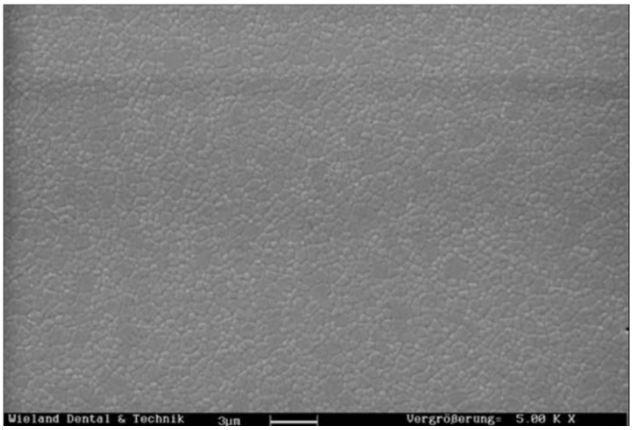

Image 23: Wieland Dental Zenostar ZrO_2 surface. (SEM)[22]

Telio PMMA differs in its structural properties, chemical composition, and fabrication process from ceramics. Because Telio is a methacrylate polymer, it's fabrication process includes free-radical polymerization under high heat and pressure to obtain a restorative material that is 99.5% PMMA. Traditional polymers like PMMA are characterized by decreased density, increased porosity, heterogeneity, increased roughness,

and a decreased degree of polymerization due to their processing. CAD/CAM available PMMA is processed in a more controlled environment, leading to an inherent increased homogeneity and an increased degree of polymerization. However, when rendered via CAD/CAM technique, telio CAD restorations are subjected to milling via diamond burs, similar to any CAD/CAM restoration fabrication. This leads to a restoration material surface that is characterized by the coarseness of the diamond bur used for milling as well as the material's structural properties. Dissimilar to ceramics though, Telio is not glazed subsequently, but rather polished to provide a final restoration.

Similar to traditional materials and past studies, the data from our study shows that our current CAD/CAM materials maintain an inability to resist residue adhesion and stainability when exposed to cigarette smoke. Independent of the material and the surface finish tested, CAD/CAM materials e.max lithium disilicate, zirconia, and telio are all susceptible to color change when exposed to the staining agent cigarette smoke. Of the available materials and surface finishes, we still do not have a material available that prevails regarding color stability and stainability, leading to the notion that further material research is needed to improve the color stability and stain-resistance of our restorative materials.

One could postulate that smoother surfaces of the CAD/CAM samples would lead to less residue adhesion when exposed to cigarette smoke compared to a rougher sample surfaces. However, for the materials where the glaze is not removed during polishing, therefore leaving a polished glazed surface (similar to image 22), residue adhesion and stainability may be indifferent to an unmodified glazed material. In our study, the polishing of both zirconia and e.max glazed samples was conducted with polishing rubber burs rather than coarse diamonds, leaving a modified glazed surface. From our study, this modification

of the glazed surface did not affect the residue adhesion and stainability of the samples exposed to cigarette smoke, as there was no statistical significance between the surface finish of the polished and glazed samples and their corresponding color changes.

5.4 Critiques and Limitations of the Study

The first limitation of this study pertains to the overall accumulation of cigarette smoke residue onto the samples' surface. Because of the nature of cigarette smoke, residue tends to accumulate in a heterogeneous manner, leading to inconsistencies within each samples' post-exposure resulting surface. To overcome this, a brushing apparatus was constructed to best remove the large accumulations of residue, further achieving a more consistently stained surface. Because we are primarily investigating the staining of the samples rather than the accumulation of tar and residue, it is important to best obtain sample surfaces that are consistent throughout each specimen.

Upon the polishing of the glazed surfaces of the zirconia and e.max specimens, the resulting surface roughness and degree of glaze removal may affect the final surface character of the specimens. Because the specimens were polished with rubber burs rather than adjusted with coarse diamond burs, the glaze was likely minimally modified. However, SEM imaging would further reveal the degree of glaze removal and resulting surface character for our specimens. Surface roughness evaluation could provide additional insight to the resulting surfaces for the specimens of this study as well. This data could potentially lead to investigation of any correlation between the surface roughness and resulting color change of our samples.

Another limitation of this study involves the environment in which the study was conducted. Because this is an in vitro study, the environment in which the smoking and soaking took place was carefully constructed to best replicate the oral environment; however, as we know, the oral environment is impossible to exactly replicate in an in vivo study. This leads to data and results that we must use only to speculate and hypothesize how materials will perform in an oral environment, assuming that in vivo situations will result similarly.

5.5 Suggestions for Future Research

In the future, the direction of this research will be expanded to investigate additional materials and additional staining exposures. With the constant development of new CAD/CAM available materials, additional research into color stability and stainability relating to newer materials is necessary. Other staining exposures, such as coffee, wine, and certain mouthrinses, would provide a more comprehensive, multi-factorial insight into the color stability and stainability of these materials as well. Additionally, increasing the sample sizes to obtain a greater power will allow further verification of this study's data and results to further substantiate our conclusions. Other considerations for the future direction of this research also include correlation to surface roughness of the samples. In our literature, we see correlations between surface preparation, roughness, stainability, and inability of stain removal; however, we would like to investigate this in relation to the modern CAD/CAM available materials as well as cigarette smoke staining.

6. CONCLUSION

In conclusion of this study, it is evident that the staining of our materials is a concern for clinicians in our field. Although modern materials have increased the homogeneity within the materials through the processing of the CAD/CAM available materials, staining is still an issue that leads to esthetic failure of our restorations over time. From the data of this study, we conclude the following:

I. When exposed to cigarette smoke, the CAD/CAM available materials of lithium disilicate, zirconia, and Telio are all susceptible to staining.

II. The polished finish of e.max lithium disilicate does not lead to increased stainability when compared to the glazed surface of e.max lithium disilicate.

III. The polished finish of zirconia does not lead to an increased stainability when compared to the glazed surface of zirconia.

IV. After exposure to cigarette smoke, all restoration materials tested that are brushed with a toothbrush exhibit a decrease in staining.

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8. APPENDIX

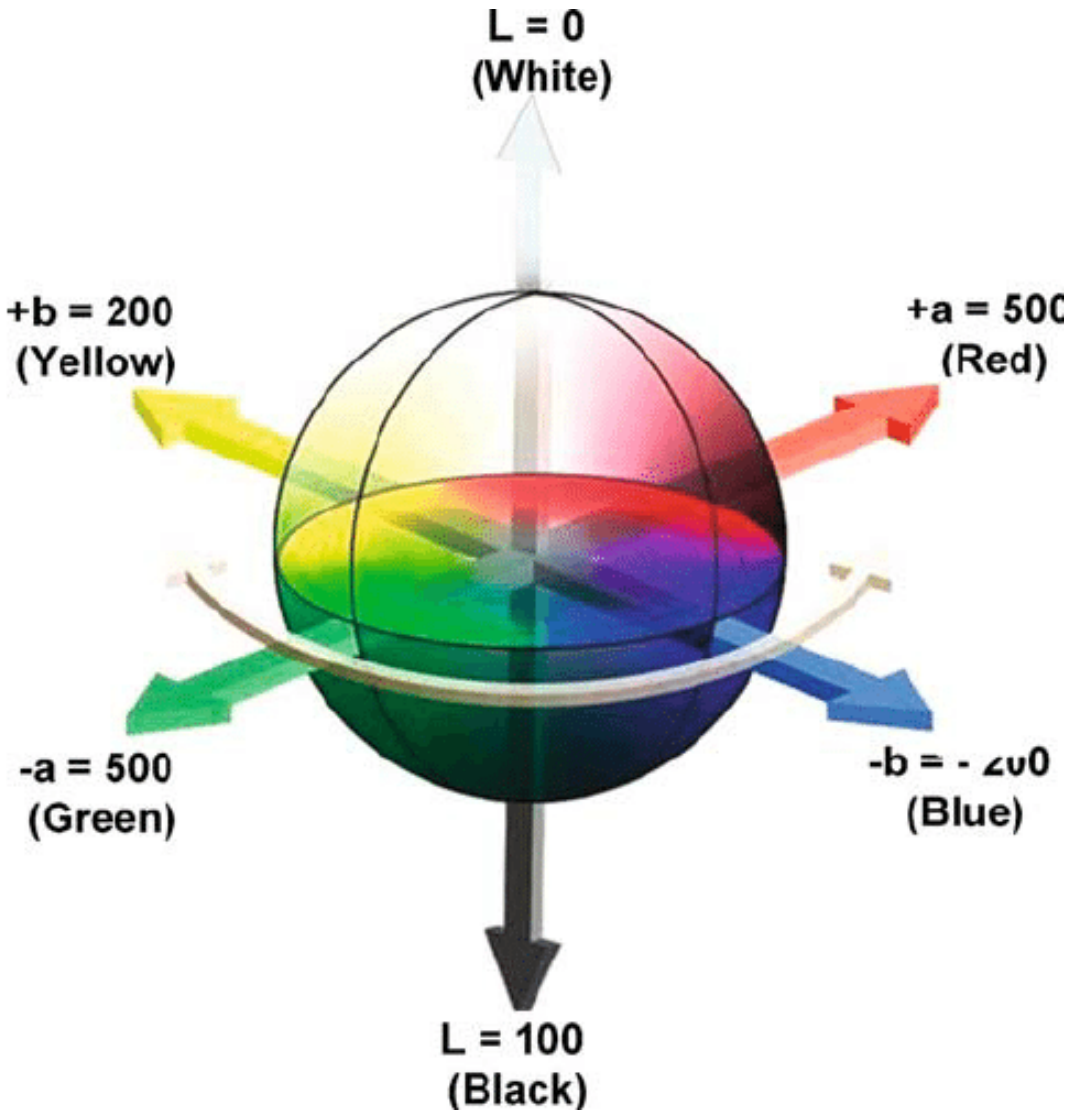

Diagram 1. CIE L*a*b* color correlation.

E.max Glazed Baseline vs After Smoking (Experimental) Colorimetry
(Table 1)

e.max G										
sp		**Baseline**			**After Smoking**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
6	69.4193	3.6959	13.3861	86.406	8.6796	9.0849	18.22	16.9867	4.9837	-4.3012
1	68.8206	3.6082	13.0729	90.2204	8.6234	6.9888	22.81	21.3998	5.0152	-6.0841
9	70.0021	3.6082	13.0772	90.8107	8.6015	6.874	22.28	20.8086	4.9933	-6.2032
7	69.3436	3.5839	13.0195	75.816	9.2447	13.6412	8.62	6.4724	5.6608	0.6217
8	69.3612	3.5899	12.9673	91.2252	8.4095	6.6079	23.27	21.864	4.8196	-6.3594
10	69.2341	3.5492	12.9856	77.7972	9.6377	17.2241	11.33	8.5631	6.0885	4.2385
2	69.3406	3.4756	12.5326	91.7344	8.4166	6.8362	23.63	22.3938	4.941	-5.6964
4	69.0818	3.425	12.3775	80.1743	8.7499	11.1303	12.37	11.0925	5.3249	-1.2472
3	69.652	3.44	12.2998	92.3335	8.445	5.5924	24.18	22.6815	5.005	-6.7074
5	69.4197	3.5263	12.4334	89.4828	8.4586	7.4129	21.26	20.0631	4.9323	-5.0205
mean	**69.37**	**3.55**	**12.82**	**86.60**	**8.73**	**9.14**	**18.80**	**17.2325**	**5.1764**	**-3.6759**
SD	**0.31**	**0.08**	**0.37**	**6.28**	**0.40**	**3.75**	**5.85**	**6.19**	**0.40**	**3.68**

E.max Polished Baseline vs After Smoking (Experimental)
(Table 2)

e.max P										
sp		**Baseline**			**After Smoking**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
11	70.0515	3.7169	13.0154	75.6015	9.8079	17.9352	9.60	5.55	6.091	4.9198
12	68.5306	3.8447	13.3267	89.2854	8.6967	9.6858	21.62	20.7548	4.852	-3.6409
13	69.5712	3.7459	12.6984	89.2276	8.5597	9.3573	20.51	19.6564	4.8138	-3.3411
14	68.693	3.7182	12.9316	86.9172	8.6231	8.9061	19.30	18.2242	4.9049	-4.0255
15	68.7095	3.791	12.9848	92.2725	8.4097	5.7088	25.09	23.563	4.6187	-7.276
16	70.0497	3.8332	12.8936	92.0728	8.7371	6.1748	23.54	22.0231	4.9039	-6.7188
17	69.2267	3.7485	12.9691	91.6657	8.6026	6.9675	23.73	22.439	4.8541	-6.0016
18	69.1981	3.7355	12.9382	76.087	9.7596	23.5154	13.99	6.8889	6.0241	10.5772
19	68.9356	3.7871	13.2372	84.8625	9.4406	13.0202	16.90	15.9269	5.6535	-0.217
20	69.035	3.7789	13.0884	86.1801	9.0226	12.2075	17.95	17.1451	5.2437	-0.8809
mean	**69.20**	**3.77**	**13.01**	**86.42**	**8.97**	**11.35**	**19.22**	**17.2171**	**5.1959**	**-1.6604**
SD	**0.54**	**0.04**	**0.18**	**6.11**	**0.52**	**5.63**	**4.81**	**6.28**	**0.54**	**5.62**

Zirconia Glazed Baseline vs After Smoking (Experimental) Colorimetry (Table 3)

Zirc G										
sp		**Baseline**			**After Smoking**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
23	88.1197	-1.0959	0.5092	91.3461	7.1259	9.9543	12.93	3.2264	8.2218	9.4451
3	88.3719	-0.8048	0.1027	108.0072	5.8754	-3.9105	21.13	19.6353	6.6802	-4.0132
2	88.5381	-0.687	-0.0826	102.2739	6.497	1.8104	15.62	13.7358	7.184	1.893
7	88.8812	-0.871	-0.102	88.5078	7.3385	17.5005	19.43	-0.3734	8.2095	17.6025
1	89.1582	-0.5917	-0.5263	111.6486	6.3088	-9.1993	25.07	22.4904	6.9005	-8.673
21	87.8384	-0.6137	-0.4375	104.2672	5.7942	2.3057	17.85	16.4288	6.4079	2.7432
8	88.477	-0.5941	-0.3966	103.715	6.5917	-1.578	16.89	15.238	7.1858	-1.1814
9	88.0256	-0.6254	-0.0715	106.7791	6.5144	-5.4621	20.78	18.7535	7.1398	-5.3906
22	88.184	-0.7487	0.2136	108.0952	6.1361	-2.5698	21.25	19.9112	6.8848	-2.7834
10	87.99	-0.7006	-0.3016	94.3582	6.9655	9.2634	13.81	6.3682	7.6661	9.565
mean	**88.36**	**-0.73**	**-0.11**	**101.90**	**6.51**	**1.81**	**18.47**	**13.5414**	**7.2480**	**1.9207**
SD	**0.42**	**0.16**	**0.32**	**7.83**	**0.51**	**8.20**	**3.77**	**7.80**	**0.61**	**8.13**

Zirconia Polished Baseline vs After Smoking (Experimental) Colorimetry (Table 4)

Zirc P										
sp		**Baseline**			**After Smoking**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
15	84.5403	-0.9271	0.1654	85.1405	7.8657	14.2616	16.62	0.6002	8.7928	14.0962
18	84.1989	-0.5825	0.0389	96.2045	6.9084	9.0869	16.80	12.0056	7.4909	9.048
12	84.3701	-0.9058	0.363	87.1958	7.572	9.5203	12.80	2.8257	8.4778	9.1573
13	83.5169	-0.8994	0.7274	96.9362	6.4193	6.9917	16.52	13.4193	7.3187	6.2643
20	84.4593	-0.9548	0.29	96.3625	6.8522	5.297	15.09	11.9032	7.807	5.007
14	83.646	-0.6787	0.0999	104.3709	6.3797	-2.1898	22.01	20.7249	7.0584	-2.2897
17	83.7112	-0.6848	0.3853	96.6582	6.6267	3.255	15.14	12.947	7.3115	2.8697
11	84.4202	-0.9794	0.5475	95.9048	6.8021	8.8466	16.17	11.4846	7.7815	8.2991
16	82.5454	-0.6472	0.1708	97.1917	6.4511	3.6271	16.64	14.6463	7.0983	3.4563
19	84.5221	-1.1205	0.1931	103.0129	6.3004	-0.4719	19.94	18.4908	7.4209	-0.665
mean	**83.99**	**-0.84**	**0.30**	**95.90**	**6.82**	**5.82**	**16.77**	**11.90**	**7.6557**	**5.5243**
SD	**0.64**	**0.18**	**0.21**	**5.94**	**0.52**	**4.96**	**2.57**	**6.17**	**0.58**	**4.92**

Telio Baseline vs After Smoking (Experimental) Colorimetry
(Table 5)

Telio										
sp		**Baseline**			**After Smoking**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
10	70.1303	6.8412	25.542	80.686	12.3721	23.6923	12.06	10.5557	5.5309	-1.8497
3	70.9751	6.9299	25.8387	68.869	14.2975	27.5254	7.85	-2.1061	7.3676	1.6867
6	70.447	7.1302	25.968	89.4399	11.2297	19.6508	20.43	18.9929	4.0995	-6.3172
7	71.1416	6.8318	25.0836	74.6296	13.7512	26.4626	7.87	3.488	6.9194	1.379
4	69.9836	6.9197	25.592	87.0224	12.0407	20.4864	18.51	17.0388	5.121	-5.1056
1	70.0277	6.8748	25.8596	68.4337	12.883	24.9483	6.28	-1.594	6.0082	-0.9113
2	70.2277	6.8539	25.5722	77.603	13.397	25.7719	9.86	7.3753	6.5431	0.1997
5	71.5188	6.8775	26.0487	79.8495	12.1528	23.5602	10.17	8.3307	5.2753	-2.4885
8	70.4588	6.8458	25.8702	87.7371	12.979	22.1462	18.71	17.2783	6.1332	-3.724
9	70.9323	6.9004	25.9794	85.3702	13.0053	22.7673	16.00	14.4379	6.1049	-3.2121
mean	**70.58**	**6.90**	**25.74**	**79.96**	**12.81**	**23.70**	**12.77**	**9.38**	**5.9103**	**-2.0343**
SD	**0.53**	**0.09**	**0.29**	**7.60**	**0.90**	**2.54**	**5.20**	**7.69**	**0.95**	**2.67**

E.max Glazed Baseline vs After Soaking (Control) Colorimetry
(Table 6)

e.max G										
sp		**Baseline**			**After Soaking**					
CONTROL	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
40	71.2415	6.5343	16.3623	70.7727	6.8917	15.0383	1.45	-0.4688	0.3574	-1.324
33	71.1973	6.6058	16.3719	70.995	7.2074	15.4714	1.10	-0.2023	0.6016	-0.9005
34	71.0451	6.6015	16.2882	71.003	7.0958	15.3034	1.10	-0.0421	0.4943	-0.9848
39	71.2839	6.441	16.2213	70.8871	6.7894	15.0227	1.31	-0.3968	0.3484	-1.1986
38	70.6248	5.9798	15.3916	70.5986	6.6169	14.5553	1.05	-0.0262	0.6371	-0.8363
32	70.7751	6.4972	16.3599	70.7801	6.9193	15.1922	1.24	0.005	0.4221	-1.1677
35	71.1746	6.5627	16.3775	70.9823	7.1316	15.3422	1.20	-0.1923	0.5689	-1.0353
31	70.4994	5.9319	15.4228	70.2358	6.7261	14.6541	1.14	-0.2636	0.7942	-0.7687
37	70.4501	6.6429	16.4993	71.7087	7.2554	15.1303	1.96	1.2586	0.6125	-1.369
36	70.7257	6.6724	16.5908	70.6836	7.3584	15.6928	1.13	-0.0421	0.686	-0.898
mean	**70.98**	**6.39**	**16.10**	**70.78**	**6.92**	**15.07**	**1.20**	**-0.20**	**0.53**	**-1.03**
SD	**0.30**	**0.28**	**0.43**	**0.26**	**0.21**	**0.33**	**0.13**	**0.17**	**0.15**	**0.19**

E.max Polished Baseline vs After Soaking (Control) Colorimetry (Table 7)

e.max P										
sp		**Baseline**			**After Soaking**					
CONTROL	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
30	69.2762	3.6123	13.2733	69.7438	5.0244	13.3745	1.49	0.4676	1.4121	0.1012
27	71.1491	6.3998	16.2858	71.106	6.848	15.1487	1.22	-0.0431	0.4482	-1.1371
21	68.7423	4.0249	13.8931	69.8669	5.4651	13.9183	1.83	1.1246	1.4402	0.0252
23	71.0702	6.5399	16.6226	71.0759	6.8481	15.3945	1.27	0.0057	0.3082	-1.2281
26	70.7323	6.2828	15.9733	71.0741	6.6997	14.9717	1.14	0.3418	0.4169	-1.0016
25	71.1792	6.5246	16.5773	71.5388	6.9129	15.3178	1.37	0.3596	0.3883	-1.2595
29	69.4702	4.0968	13.6786	70.9272	7.0662	15.2976	3.68	1.457	2.9694	1.619
24	70.2522	6.1603	15.758	71.0153	6.5026	14.6871	1.36	0.7631	0.3423	-1.0709
22	70.8358	6.5391	16.5187	71.3609	7.2014	15.7457	1.15	0.5251	0.6623	-0.773
28	71.5798	6.8347	17.1511	71.3256	7.2482	15.9059	1.34	-0.2542	0.4135	-1.2452
mean	**70.43**	**5.70**	**15.57**	**70.90**	**6.58**	**14.98**	**1.58**	**0.4747**	**0.8801**	**-0.597**
SD	**0.95**	**1.25**	**1.41**	**0.61**	**0.75**	**0.79**	**0.76**	**0.53**	**0.85**	**0.93**

Zirconia Glazed Baseline vs After Soaking (Control) Colorimetry
(Table 8)

Zirc G										
sp		**Baseline**			**After Soaking**					
CONTROL	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
24	97.1472	-0.1405	0.5208	92.2233	0.3325	-0.4503	5.04	-4.9239	0.473	-0.9711
26	97.1432	-0.2175	0.7171	92.5091	0.2419	-0.3678	4.78	-4.6341	0.4594	-1.0849
28	96.6885	-0.1004	0.5386	90.1942	0.2735	-0.8974	6.66	-6.4943	0.3739	-1.436
121	95.6902	0.0669	0.2832	91.6704	0.3293	-0.8063	4.17	-4.0198	0.2624	-1.0895
29	97.3114	-0.1421	0.4305	93.3452	0.2756	-0.6097	4.12	-3.9662	0.4177	-1.0402
123	97.2031	-0.1663	0.5775	95.3484	0.2694	-0.0078	1.99	-1.8547	0.4357	-0.5853
30	96.9783	-0.1462	0.6097	91.9946	0.2992	-0.4284	5.11	-4.9837	0.4454	-1.0381
27	97.2054	-0.1913	0.7146	94.9361	0.2653	-0.1549	2.47	-2.2693	0.4566	-0.8695
25	97.8087	-0.1342	0.5484	90.9445	0.2736	-0.4545	6.95	-6.8642	0.4078	-1.0029
122	96.5505	0.0925	0.1965	92.2033	0.3439	-0.7881	4.46	-4.3472	0.2514	-0.9846
mean	**97.02**	**-0.13**	**0.55**	**92.57**	**0.28**	**-0.46**	**4.59**	**-4.45**	**0.4146**	**-1.01**
SD	**0.58**	**0.08**	**0.13**	**1.71**	**0.03**	**0.28**	**1.66**	**1.68**	**0.06**	**0.22**

Zirconia Polished Baseline vs After Soaking (Control) Colorimetry (Table 9)

Zirc P										
sp		**Baseline**			**After Soaking**					
CONTROL	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
38	92.5772	-1.3104	3.1311	86.6374	-0.9485	1.8338	6.09	-5.9398	0.3619	-1.2973
33	92.3644	-0.4924	1.6614	87.5102	-0.0642	0.0347	5.14	-4.8542	0.4282	-1.6267
31	92.0248	-0.2742	0.9173	90.0886	-0.1345	-0.4315	2.36	-1.9362	0.1397	-1.3488
32	92.3633	-0.7525	2.0498	88.1826	-0.4516	0.9704	4.33	-4.1807	0.3009	-1.0794
36	92.1105	-0.1338	0.8266	88.3475	0.1506	-0.2816	3.93	-3.763	0.2844	-1.1082
39	92.8985	-0.915	2.544	88.5336	-0.601	1.1167	4.60	-4.3649	0.314	-1.4273
35	92.7018	-0.3389	1.0998	88.1246	0.0237	-0.0749	4.74	-4.5772	0.3626	-1.1747
34	91.679	-0.4205	1.5864	88.3272	-0.0487	0.333	3.60	-3.3518	0.3718	-1.2534
40	91.8978	-0.3188	1.2049	86.941	0.0629	-0.1563	5.15	-4.9568	0.3817	-1.3612
37	92.5299	-0.4783	1.4315	87.2238	-0.1705	0.3938	5.42	-5.3061	0.3078	-1.0377
mean	**92.29**	**-0.55**	**1.67**	**88.08**	**-0.22**	**0.37**	**4.44**	**-4.21**	**0.3272**	**-1.30**
SD	**0.40**	**0.37**	**0.78**	**1.01**	**0.37**	**0.77**	**1.07**	**1.13**	**0.08**	**0.17**

Telio Baseline vs After Soaking (Control) Colorimetry
(Table 10)

Telio										
sp		**Baseline**			**After Soaking**					
CONTROL	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
20	77.0749	11.3861	36.362	74.1867	11.6462	30.8663	6.21	-2.8882	0.2601	-5.4957
11	77.7536	10.9335	35.8816	75.0116	12.0075	31.8622	4.98	-2.742	1.074	-4.0194
15	78.1997	10.9038	35.7405	75.1295	11.7856	31.599	5.23	-3.0702	0.8818	-4.1415
13	76.9213	11.3797	35.733	74.9908	12.8797	32.697	3.90	-1.9305	1.5	-3.036
14	77.449	11.2497	35.8782	75.2631	12.5233	32.2713	4.41	-2.1859	1.2736	-3.6069
16	77.4847	11.0628	35.7686	75.6163	11.8737	30.9604	5.22	-1.8684	0.8109	-4.8082
12	80.1018	9.8057	37.0104	79.0125	12.5796	36.0839	3.12	-1.0893	2.7739	-0.9265
17	77.2183	10.9587	36.2508	74.6053	11.3731	30.8979	5.97	-2.613	0.4144	-5.3529
18	78.0104	10.9708	36.4152	74.8278	11.572	31.433	5.94	-3.1826	0.6012	-4.9822
19	77.1879	11.3783	33.8974	73.4725	12.0879	30.4523	5.12	-3.7154	0.7096	-3.4451
mean	**77.74**	**11.00**	**35.89**	**75.21**	**12.03**	**31.91**	**5.01**	**-2.5285**	**1.02995**	**-3.9814**
SD	**0.93**	**0.46**	**0.81**	**1.46**	**0.49**	**1.62**	**0.97**	**0.77**	**0.72**	**1.36**

E.max Glazed Baseline vs After Brushing (Experimental) Colorimetry (Table 11)

e.max G										
sp		**Baseline**			**After Brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
6	69.4193	3.6959	13.3861	69.4856	5.464	14.9073	2.33	0.0663	1.7681	1.5212
1	68.8206	3.6082	13.0729	69.1021	5.2267	14.3427	2.08	0.2815	1.6185	1.2698
9	70.0021	3.6082	13.0772	69.651	5.4901	14.6285	2.46	-0.3511	1.8819	1.5513
7	69.3436	3.5839	13.0195	69.4131	5.4136	14.9294	2.65	0.0695	1.8297	1.9099
8	69.3612	3.5899	12.9673	69.7799	5.3472	14.561	2.41	0.4187	1.7573	1.5937
10	69.2341	3.5492	12.9856	68.4053	5.6253	15.5962	3.44	-0.8288	2.0761	2.6106
2	69.3406	3.4756	12.5326	69.5029	5.2309	14.1024	2.36	0.1623	1.7553	1.5698
4	69.0818	3.425	12.3775	68.6391	4.8699	13.7565	2.05	-0.4427	1.4449	1.379
3	69.652	3.44	12.2998	69.8692	5.1238	13.9764	2.39	0.2172	1.6838	1.6766
5	69.4197	3.5263	12.4334	69.3652	5.2272	14.088	2.37	-0.0545	1.7009	1.6546
mean	**69.37**	**3.55**	**12.82**	**69.32**	**5.30**	**14.49**	**2.45**	**-0.0461**	**1.7516**	**1.6736**
SD	**0.31**	**0.08**	**0.37**	**0.48**	**0.21**	**0.55**	**0.39**	**0.38**	**0.17**	**0.37**

E.max Polished Baseline vs After Brushing (Experimental) Colorimetry (Table 12)

e.max P										
sp		**Baseline**			**After Brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
11	70.0515	3.7169	13.0154	65.007	6.354	20.1534	9.13	-5.0445	2.6371	7.138
12	68.5306	3.8447	13.3267	68.1696	5.3072	16.8354	3.82	-0.361	1.4625	3.5087
13	69.5712	3.7459	12.6984	68.6291	5.3312	16.1493	3.91	-0.9421	1.5853	3.4509
14	68.693	3.7182	12.9316	68.8164	5.5153	15.4371	3.09	0.1234	1.7971	2.5055
15	68.7095	3.791	12.9848	69.2517	5.3027	14.7837	2.41	0.5422	1.5117	1.7989
16	70.0497	3.8332	12.8936	69.7903	5.4274	14.8173	2.51	-0.2594	1.5942	1.9237
17	69.2267	3.7485	12.9691	69.2237	5.4279	15.1825	2.78	-0.003	1.6794	2.2134
18	69.1981	3.7355	12.9382	61.3495	6.9463	24.719	14.52	-7.8486	3.2108	11.7808
19	68.9356	3.7871	13.2372	67.632	6.112	17.1412	4.73	-1.3036	2.3249	3.904
20	69.035	3.7789	13.0884	66.2135	5.7884	17.8186	5.86	-2.8215	2.0095	4.7302
mean	**69.20**	**3.77**	**13.01**	**67.41**	**5.75**	**17.30**	**5.28**	**-1.7918**	**1.9812**	**4.2954**
SD	**0.54**	**0.04**	**0.18**	**2.59**	**0.55**	**3.08**	**3.83**	**2.71**	**0.58**	**3.08**

Zirconia Glazed Baseline vs After Brushing (Experimental) Colorimetry (Table 13)

Zirc G										
sp		**Baseline**			**After Brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
23	88.1197	-1.0959	0.5092	90.5286	0.6569	3.8684	4.49	2.4089	1.7528	3.3592
3	88.3719	-0.8048	0.1027	84.3839	1.2937	9.1335	10.09	-3.988	2.0985	9.0308
2	88.5381	-0.687	-0.0826	87.4694	0.8691	10.3544	10.61	-1.0687	1.5561	10.437
7	88.8812	-0.871	-0.102	85.2314	1.4715	12.9366	13.74	-3.6498	2.3425	13.0386
1	89.1582	-0.5917	-0.5263	92.8082	0.5372	2.266	4.73	3.65	1.1289	2.7923
21	87.8384	-0.6137	-0.4375	90.6216	0.6406	5.4375	6.62	2.7832	1.2543	5.875
8	88.477	-0.5941	-0.3966	92.1759	0.4504	3.7622	5.66	3.6989	1.0445	4.1588
9	88.0256	-0.6254	-0.0715	89.8619	0.7725	5.4595	5.99	1.8363	1.3979	5.531
22	88.184	-0.7487	0.2136	91.6408	0.6887	5.3285	6.34	3.4568	1.4374	5.1149
10	87.99	-0.7006	-0.3016	85.5785	1.5213	10.1881	10.99	-2.4115	2.2219	10.4897
mean	**88.36**	**-0.73**	**-0.11**	**89.03**	**0.89**	**6.87**	**7.93**	**0.6716**	**1.6234**	**6.9827**
SD	**0.42**	**0.16**	**0.32**	**3.11**	**0.39**	**3.52**	**3.17**	**3.12**	**0.46**	**3.51**

Zirconia Polished Baseline vs After Brushing (Experimental) Colorimetry (Table 14)

Zirc P										
sp		**Baseline**			**After Brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
15	84.5403	-0.9271	0.1654	81.6978	1.6623	7.8559	8.60	-2.8425	2.5894	7.6905
18	84.1989	-0.5825	0.0389	87.5321	0.5984	7.3267	8.10	3.3332	1.1809	7.2878
12	84.3701	-0.9058	0.363	80.0877	2.1848	10.8629	11.75	-4.2824	3.0906	10.4999
13	83.5169	-0.8994	0.7274	82.054	1.6048	12.2019	11.84	-1.4629	2.5042	11.4745
20	84.4593	-0.9548	0.29	89.4264	0.3457	6.9377	8.40	4.9671	1.3005	6.6477
14	83.646	-0.6787	0.0999	88.1263	0.6841	6.49	7.92	4.4803	1.3628	6.3901
17	83.7112	-0.6848	0.3853	86.8752	0.7102	8.6724	8.98	3.164	1.395	8.2871
11	84.4202	-0.9794	0.5475	82.5321	1.5226	11.4181	11.31	-1.8881	2.502	10.8706
16	82.5454	-0.6472	0.1708	84.5534	1.55	11.6103	11.82	2.008	2.1972	11.4395
19	84.5221	-1.1205	0.1931	86.7411	0.8626	7.2339	7.64	2.219	1.9831	7.0408
mean	**83.99**	**-0.84**	**0.30**	**84.96**	**1.17**	**9.06**	**9.64**	**0.97**	**2.0105**	**8.7628**
SD	**0.64**	**0.18**	**0.21**	**3.20**	**0.60**	**2.22**	**1.80**	**3.29**	**0.67**	**2.07**

Telio Baseline vs After Brushing (Experimental) Colorimetry
(Table 15)

Telio										
sp		**Baseline**			**After Brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
10	70.1303	6.8412	25.542	68.0427	11.1456	30.4313	6.84	-2.0876	4.3044	4.8893
3	70.9751	6.9299	25.8387	65.5342	12.614	33.2362	10.80	-5.4409	5.6841	7.3975
6	70.447	7.1302	25.968	70.2631	10.9736	29.8629	5.48	-0.1839	3.8434	3.8949
7	71.1416	6.8318	25.0836	61.9745	13.1342	33.4359	13.91	-9.1671	6.3024	8.3523
4	69.9836	6.9197	25.592	70.1084	11.9696	30.8489	7.29	0.1248	5.0499	5.2569
1	70.0277	6.8748	25.8596	64.6244	11.1919	30.5708	8.37	-5.4033	4.3171	4.7112
2	70.2277	6.8539	25.5722	66.6988	12.3705	32.8264	9.77	-3.5289	5.5166	7.2542
5	71.5188	6.8775	26.0487	66.7466	11.9501	32.2592	9.33	-4.7722	5.0726	6.2105
8	70.4588	6.8458	25.8702	71.0481	12.99	29.5793	7.20	0.5893	6.1442	3.7091
9	70.9323	6.9004	25.9794	69.791	12.8688	31.4989	8.21	-1.1413	5.9684	5.5195
mean	**70.58**	**6.90**	**25.74**	**67.48**	**12.12**	**31.45**	**8.72**	**-3.10**	**5.2203**	**5.7195**
SD	**0.53**	**0.09**	**0.29**	**2.91**	**0.80**	**1.41**	**2.39**	**3.13**	**0.85**	**1.55**

E.max Glazed Baseline vs After Brushing (Control) Colorimetry (Table 16)

e.max G										
sp		**Baseline**			**After brushing**					
CONTROL	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
40	71.2415	6.5343	16.3623	70.5086	6.3987	16.3471	0.75	-0.7329	-0.1356	-0.0152
33	71.1973	6.6058	16.3719	70.4815	6.2999	16.0759	0.83	-0.7158	-0.3059	-0.296
34	71.0451	6.6015	16.2882	70.6532	6.1503	15.9873	0.67	-0.3919	-0.4512	-0.3009
39	71.2839	6.441	16.2213	70.9878	5.8288	15.741	0.83	-0.2961	-0.6122	-0.4803
38	70.6248	5.9798	15.3916	70.6659	5.6825	15.2327	0.34	0.0411	-0.2973	-0.1589
32	70.7751	6.4972	16.3599	70.669	5.9825	15.9055	0.69	-0.1061	-0.5147	-0.4544
35	71.1746	6.5627	16.3775	71.0077	6.2333	16.0155	0.52	-0.1669	-0.3294	-0.362
31	70.4994	5.9319	15.4228	70.3172	5.911	15.3825	0.19	-0.1822	-0.0209	-0.0403
37	70.4501	6.6429	16.4993	71.2496	6.2754	15.8119	1.12	0.7995	-0.3675	-0.6874
36	70.7257	6.6724	16.5908	71.0783	5.9699	15.7757	1.13	0.3526	-0.7025	-0.8151
mean	**70.98**	**6.39**	**16.10**	**70.66**	**6.06**	**15.84**	**0.60**	**-0.32**	**-0.33**	**-0.2635**
SD	**0.30**	**0.28**	**0.43**	**0.24**	**0.25**	**0.37**	**0.24**	**0.28**	**0.19**	**0.18**

E.max Polished Baseline vs After Brushing (Control) Colorimetry (Table 17)

e.max P										
sp		**Baseline**			**After brushing**					
CONTROL	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
30	69.2762	3.6123	13.2733	70.0073	4.1434	13.7658	1.03	0.7311	0.5311	0.4925
27	71.1491	6.3998	16.2858	71.5212	5.9634	15.99	0.65	0.3721	-0.4364	-0.2958
21	68.7423	4.0249	13.8931	70.3393	4.5397	14.3759	1.75	1.597	0.5148	0.4828
23	71.0702	6.5399	16.6226	72.1106	5.8765	15.9653	1.40	1.0404	-0.6634	-0.6573
26	70.7323	6.2828	15.9733	71.5044	5.8312	15.6379	0.96	0.7721	-0.4516	-0.3354
25	71.1792	6.5246	16.5773	71.8816	5.9337	15.8901	1.15	0.7024	-0.5909	-0.6872
29	69.4702	4.0968	13.6786	71.4477	6.203	15.9662	3.69	1.9775	2.1062	2.2876
24	70.2522	6.1603	15.758	70.9812	5.6218	15.3937	0.98	0.729	-0.5385	-0.3643
22	70.8358	6.5391	16.5187	71.972	6.2137	16.1813	1.23	1.1362	-0.3254	-0.3374
28	71.5798	6.8347	17.1511	71.897	6.2636	16.5335	0.90	0.3172	-0.5711	-0.6176
mean	**70.43**	**5.70**	**15.57**	**71.37**	**5.66**	**15.57**	**1.37**	**0.9375**	**-0.0425**	**-0.0032**
SD	**0.95**	**1.25**	**1.41**	**0.71**	**0.73**	**0.86**	**0.87**	**0.52**	**0.87**	**0.91**

Zirconia Glazed Baseline vs After Brushing (Control) Colorimetry
(Table 18)

Zirc G										
sp		**Baseline**			**After brushing**					
CONTROL	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
24	97.1472	-0.1405	0.5208	93.2504	0.0067	-0.172	3.96	-3.8968	0.1472	-0.6928
26	97.1432	-0.2175	0.7171	93.437	-0.1004	0.0049	3.78	-3.7062	0.1171	-0.7122
28	96.6885	-0.1004	0.5386	91.6753	-0.0769	-0.6045	5.14	-5.0132	0.0235	-1.1431
121	95.6902	0.0669	0.2832	92.4779	0.0137	-0.4493	3.30	-3.2123	-0.0532	-0.7325
29	97.3114	-0.1421	0.4305	93.0281	-0.0404	-0.0792	4.31	-4.2833	0.1017	-0.5097
123	97.2031	-0.1663	0.5775	95.8159	-0.0609	0.1735	1.45	-1.3872	0.1054	-0.404
30	96.9783	-0.1462	0.6097	93.0959	-0.0096	-0.2976	3.99	-3.8824	0.1366	-0.9073
27	97.2054	-0.1913	0.7146	94.1278	-0.0259	0.2144	3.12	-3.0776	0.1654	-0.5002
25	97.8087	-0.1342	0.5484	93.4864	-0.0404	-0.3312	4.41	-4.3223	0.0938	-0.8796
122	96.5505	0.0925	0.1965	93.6599	0.0477	-0.4082	2.95	-2.8906	-0.0448	-0.6047
mean	**97.02**	**-0.13**	**0.55**	**93.38**	**-0.04**	**-0.17**	**3.72**	**-3.64**	**0.09305**	**-0.72**
SD	**0.58**	**0.08**	**0.13**	**1.14**	**0.04**	**0.28**	**1.04**	**1.03**	**0.07**	**0.23**

Zirconia Polished Baseline vs After Brushing (Control) Colorimetry (Table 19)

Zirc P										
sp		**Baseline**			**After brushing**					
CONTROL	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
38	92.5772	-1.3104	3.1311	86.7196	-1.2606	2.3523	5.91	-5.8576	0.0498	-0.7788
33	92.3644	-0.4924	1.6614	87.518	-0.4571	0.3599	5.02	-4.8464	0.0353	-1.3015
31	92.0248	-0.2742	0.9173	90.7033	-0.4525	0.0208	1.61	-1.3215	-0.1783	-0.8965
32	92.3633	-0.7525	2.0498	88.4931	-0.7045	1.4314	3.92	-3.8702	0.048	-0.6184
36	92.1105	-0.1338	0.8266	88.57	-0.1642	0.3611	3.57	-3.5405	-0.0304	-0.4655
39	92.8985	-0.915	2.544	88.3277	-0.929	1.7717	4.64	-4.5708	-0.014	-0.7723
35	92.7018	-0.3389	1.0998	87.8771	-0.3053	0.4231	4.87	-4.8247	0.0336	-0.6767
34	91.679	-0.4205	1.5864	87.9791	-0.427	1.0429	3.74	-3.6999	-0.0065	-0.5435
40	91.8978	-0.3188	1.2049	86.9879	-0.2436	0.5451	4.95	-4.9099	0.0752	-0.6598
37	92.5299	-0.4783	1.4315	87.683	-0.4639	1.0035	4.87	-4.8469	0.0144	-0.428
mean	**92.29**	**-0.55**	**1.67**	**88.13**	**-0.55**	**0.92**	**4.25**	**-4.16**	**0.0014**	**-0.75**
SD	**0.40**	**0.37**	**0.78**	**1.16**	**0.36**	**0.78**	**1.23**	**1.29**	**0.08**	**0.25**

Telio Baseline vs After Brushing (Control) Colorimetry
(Table 20)

Telio										
sp		**Baseline**			**After brushing**					
CONTROL	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
20	77.0749	11.3861	36.362	74.7372	9.2741	32.0874	5.31	-2.3377	-2.112	-4.2746
11	77.7536	10.9335	35.8816	76.0542	9.3867	32.7163	3.91	-1.6994	-1.5468	-3.1653
15	78.1997	10.9038	35.7405	75.6987	9.2504	32.5898	4.35	-2.501	-1.6534	-3.1507
13	76.9213	11.3797	35.733	75.9699	10.2123	33.6133	2.60	-0.9514	-1.1674	-2.1197
14	77.449	11.2497	35.8782	76.1673	9.9721	33.2787	3.17	-1.2817	-1.2776	-2.5995
16	77.4847	11.0628	35.7686	75.891	9.5931	32.7856	3.69	-1.5937	-1.4697	-2.983
12	80.1018	9.8057	37.0104	80.0112	9.6643	37.0046	0.17	-0.0906	-0.1414	-0.0058
17	77.2183	10.9587	36.2508	75.3398	8.8265	31.7938	5.29	-1.8785	-2.1322	-4.457
18	78.0104	10.9708	36.4152	75.0849	8.8212	31.5259	6.09	-2.9255	-2.1496	-4.8893
19	77.1879	11.3783	33.8974	74.2257	9.6146	31.36	4.28	-2.9622	-1.7637	-2.5374
mean	**77.74**	**11.00**	**35.89**	**75.92**	**9.46**	**32.88**	**3.89**	**-1.8221**	**-1.5413**	**-3.0182**
SD	**0.93**	**0.46**	**0.81**	**1.57**	**0.45**	**1.63**	**1.67**	**0.90**	**0.60**	**1.39**

E.max Glazed After Smoking vs After Brushing (Experimental) Colorimetry (Table 21)

e.max G										
sp		**After Smoking**			**After Brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
6	86.406	8.6796	9.0849	69.4856	5.464	14.9073	18.18	-16.9204	-3.2156	5.8224
1	90.2204	8.6234	6.9888	69.1021	5.2267	14.3427	22.62	-21.1183	-3.3967	7.3539
9	90.8107	8.6015	6.874	69.651	5.4901	14.6285	22.75	-21.1597	-3.1114	7.7545
7	75.816	9.2447	13.6412	69.4131	5.4136	14.9294	7.57	-6.4029	-3.8311	1.2882
8	91.2252	8.4095	6.6079	69.7799	5.3472	14.561	23.08	-21.4453	-3.0623	7.9531
10	77.7972	9.6377	17.2241	68.4053	5.6253	15.5962	10.34	-9.3919	-4.0124	-1.6279
2	91.7344	8.4166	6.8362	69.5029	5.2309	14.1024	23.60	-22.2315	-3.1857	7.2662
4	80.1743	8.7499	11.1303	68.6391	4.8699	13.7565	12.45	-11.5352	-3.88	2.6262
3	92.3335	8.445	5.5924	69.8692	5.1238	13.9764	24.21	-22.4643	-3.3212	8.384
5	89.4828	8.4586	7.4129	69.3652	5.2272	14.088	21.44	-20.1176	-3.2314	6.6751
mean	**86.60**	**8.73**	**9.14**	**69.32**	**5.30**	**14.49**	**18.62**	**-17.2787**	**-3.4247**	**5.3495**
SD	**6.28**	**0.40**	**3.75**	**0.48**	**0.21**	**0.55**	**6.20**	**5.97**	**0.35**	**3.40**

E.max Polished After Smoking vs After Brushing (Experimental) Colorimetry (Table 22)

e.max P										
sp		**After Smoking**			**After Brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
11	75.6015	9.8079	17.9352	65.007	6.354	20.1534	11.36	-10.5945	-3.4539	2.2182
12	89.2854	8.6967	9.6858	68.1696	5.3072	16.8354	22.55	-21.1158	-3.3895	7.1496
13	89.2276	8.5597	9.3573	68.6291	5.3312	16.1493	21.93	-20.5985	-3.2285	6.792
14	86.9172	8.6231	8.9061	68.8164	5.5153	15.4371	19.49	-18.1008	-3.1078	6.531
15	92.2725	8.4097	5.7088	69.2517	5.3027	14.7837	24.94	-23.0208	-3.107	9.0749
16	92.0728	8.7371	6.1748	69.7903	5.4274	14.8173	24.13	-22.2825	-3.3097	8.6425
17	91.6657	8.6026	6.9675	69.2237	5.4279	15.1825	24.11	-22.442	-3.1747	8.215
18	76.087	9.7596	23.5154	61.3495	6.9463	24.719	15.05	-14.7375	-2.8133	1.2036
19	84.8625	9.4406	13.0202	67.632	6.112	17.1412	18.03	-17.2305	-3.3286	4.121
20	86.1801	9.0226	12.2075	66.2135	5.7884	17.8186	20.99	-19.9666	-3.2342	5.6111
mean	**86.42**	**8.97**	**11.35**	**67.41**	**5.75**	**17.30**	**20.26**	**-19.0089**	**-3.2147**	**5.9558**
SD	**6.11**	**0.52**	**5.63**	**2.59**	**0.55**	**3.08**	**4.37**	**3.94**	**0.18**	**2.68**

Zirconia Glazed After Smoking vs After Brushing (Experimental) Colorimetry (Table 23)

Zirc G										
sp		**After Smoking**			**After Brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
23	91.3461	7.1259	9.9543	90.5286	0.6569	3.8684	8.92	-0.8175	-6.469	-6.0859
3	108.0072	5.8754	-3.9105	84.3839	1.2937	9.1335	27.37	-23.6233	-4.5817	13.044
2	102.2739	6.497	1.8104	87.4694	0.8691	10.3544	18.00	-14.8045	-5.6279	8.544
7	88.5078	7.3385	17.5005	85.2314	1.4715	12.9366	8.12	-3.2764	-5.867	-4.5639
1	111.6486	6.3088	-9.1993	92.8082	0.5372	2.266	22.80	-18.8404	-5.7716	11.4653
21	104.2672	5.7942	2.3057	90.6216	0.6406	5.4375	14.92	-13.6456	-5.1536	3.1318
8	103.715	6.5917	-1.578	92.1759	0.4504	3.7622	14.12	-11.5391	-6.1413	5.3402
9	106.7791	6.5144	-5.4621	89.8619	0.7725	5.4595	20.94	-16.9172	-5.7419	10.9216
22	108.0952	6.1361	-2.5698	91.6408	0.6887	5.3285	19.05	-16.4544	-5.4474	7.8983
10	94.3582	6.9655	9.2634	85.5785	1.5213	10.1881	10.37	-8.7797	-5.4442	0.9247
mean	**101.90**	**6.51**	**1.81**	**89.03**	**0.89**	**6.87**	**16.46**	**-12.8698**	**-5.6245**	**5.0620**
SD	**7.83**	**0.51**	**8.20**	**3.11**	**0.39**	**3.52**	**6.32**	**7.00**	**0.52**	**6.64**

Zirconia Polished After Smoking vs After Brushing (Experimental) Colorimetry (Table 24)

Zirc P										
sp		**After Smoking**			**After Brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
15	85.1405	7.8657	14.2616	81.6978	1.6623	7.8559	9.56	-3.4427	-6.2034	-6.4057
18	96.2045	6.9084	9.0869	87.5321	0.5984	7.3267	10.87	-8.6724	-6.31	-1.7602
12	87.1958	7.572	9.5203	80.0877	2.1848	10.8629	9.02	-7.1081	-5.3872	1.3426
13	96.9362	6.4193	6.9917	82.054	1.6048	12.2019	16.49	-14.8822	-4.8145	5.2102
20	96.3625	6.8522	5.297	89.4264	0.3457	6.9377	9.65	-6.9361	-6.5065	1.6407
14	104.3709	6.3797	-2.1898	88.1263	0.6841	6.49	19.28	-16.2446	-5.6956	8.6798
17	96.6582	6.6267	3.255	86.8752	0.7102	8.6724	12.65	-9.783	-5.9165	5.4174
11	95.9048	6.8021	8.8466	82.5321	1.5226	11.4181	14.61	-13.3727	-5.2795	2.5715
16	97.1917	6.4511	3.6271	84.5534	1.55	11.6103	15.73	-12.6383	-4.9011	7.9832
19	103.0129	6.3004	-0.4719	86.7411	0.8626	7.2339	18.81	-16.2718	-5.4378	7.7058
mean	**95.90**	**6.82**	**5.82**	**84.96**	**1.17**	**9.06**	**13.67**	**-10.94**	**-5.6452**	**3.2385**
SD	**5.94**	**0.52**	**4.96**	**3.20**	**0.60**	**2.22**	**3.87**	**4.40**	**0.58**	**4.78**

Telio After Smoking vs After Brushing (Experimental) Colorimetry (Table 25)

Telio										
sp		**After Smoking**			**After Brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
10	80.686	12.3721	23.6923	68.0427	11.1456	30.4313	14.38	-12.6433	-1.2265	6.739
3	68.869	14.2975	27.5254	65.5342	12.614	33.2362	6.82	-3.3348	-1.6835	5.7108
6	89.4399	11.2297	19.6508	70.2631	10.9736	29.8629	21.73	-19.1768	-0.2561	10.2121
7	74.6296	13.7512	26.4626	61.9745	13.1342	33.4359	14.46	-12.6551	-0.617	6.9733
4	87.0224	12.0407	20.4864	70.1084	11.9696	30.8489	19.84	-16.914	-0.0711	10.3625
1	68.4337	12.883	24.9483	64.6244	11.1919	30.5708	7.00	-3.8093	-1.6911	5.6225
2	77.603	13.397	25.7719	66.6988	12.3705	32.8264	13.03	-10.9042	-1.0265	7.0545
5	79.8495	12.1528	23.5602	66.7466	11.9501	32.2592	15.73	-13.1029	-0.2027	8.699
8	87.7371	12.979	22.1462	71.0481	12.99	29.5793	18.27	-16.689	0.011	7.4331
9	85.3702	13.0053	22.7673	69.791	12.8688	31.4989	17.86	-15.5792	-0.1365	8.7316
mean	**79.96**	**12.81**	**23.70**	**67.48**	**12.12**	**31.45**	**14.91**	**-12.48**	**-0.69**	**7.7538**
SD	**7.60**	**0.90**	**2.54**	**2.91**	**0.80**	**1.41**	**4.98**	**5.31**	**0.67**	**1.69**

E.max Glazed After Soaking vs After Brushing (Control) Colorimetry (Table 26)

e.max G										
sp		**After Soaking**			**After brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
40	70.7727	6.8917	15.0383	70.5086	6.3987	16.3471	1.42	-0.2641	-0.493	1.3088
33	70.995	7.2074	15.4714	70.4815	6.2999	16.0759	1.21	-0.5135	-0.9075	0.6045
34	71.003	7.0958	15.3034	70.6532	6.1503	15.9873	1.22	-0.3498	-0.9455	0.6839
39	70.8871	6.7894	15.0227	70.9878	5.8288	15.741	1.20	0.1007	-0.9606	0.7183
38	70.5986	6.6169	14.5553	70.6659	5.6825	15.2327	1.16	0.0673	-0.9344	0.6774
32	70.7801	6.9193	15.1922	70.669	5.9825	15.9055	1.18	-0.1111	-0.9368	0.7133
35	70.9823	7.1316	15.3422	71.0077	6.2333	16.0155	1.12	0.0254	-0.8983	0.6733
31	70.2358	6.7261	14.6541	70.3172	5.911	15.3825	1.10	0.0814	-0.8151	0.7284
37	71.7087	7.2554	15.1303	71.2496	6.2754	15.8119	1.28	-0.4591	-0.98	0.6816
36	70.6836	7.3584	15.6928	71.0783	5.9699	15.7757	1.45	0.3947	-1.3885	0.0829
mean	**70.78**	**6.92**	**15.07**	**70.66**	**6.06**	**15.84**	**1.20**	**-0.12**	**-0.86**	**0.7634**
SD	**0.26**	**0.21**	**0.33**	**0.24**	**0.25**	**0.37**	**0.10**	**0.23**	**0.16**	**0.22**

E.max Polished After Soaking vs After Brushing (Control) Colorimetry (Table 27)

e.max P										
sp		**After Soaking**			**After brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
30	69.7438	5.0244	13.3745	70.0073	4.1434	13.7658	1.00	0.2635	-0.881	0.3913
27	71.106	6.848	15.1487	71.5212	5.9634	15.99	1.29	0.4152	-0.8846	0.8413
21	69.8669	5.4651	13.9183	70.3393	4.5397	14.3759	1.14	0.4724	-0.9254	0.4576
23	71.0759	6.8481	15.3945	72.1106	5.8765	15.9653	1.53	1.0347	-0.9716	0.5708
26	71.0741	6.6997	14.9717	71.5044	5.8312	15.6379	1.18	0.4303	-0.8685	0.6662
25	71.5388	6.9129	15.3178	71.8816	5.9337	15.8901	1.18	0.3428	-0.9792	0.5723
29	70.9272	7.0662	15.2976	71.4477	6.203	15.9662	1.21	0.5205	-0.8632	0.6686
24	71.0153	6.5026	14.6871	70.9812	5.6218	15.3937	1.13	-0.0341	-0.8808	0.7066
22	71.3609	7.2014	15.7457	71.972	6.2137	16.1813	1.24	0.6111	-0.9877	0.4356
28	71.3256	7.2482	15.9059	71.897	6.2636	16.5335	1.30	0.5714	-0.9846	0.6276
mean	**70.90**	**6.58**	**14.98**	**71.37**	**5.66**	**15.57**	**1.22**	**0.4627**	**-0.9226**	**0.5937**
SD	**0.61**	**0.75**	**0.79**	**0.71**	**0.73**	**0.86**	**0.14**	**0.27**	**0.05**	**0.14**

Zirconia Glazed After Soaking vs After Brushing (Control) Colorimetry (Table 28)

Zirc G										
sp		**After Soaking**			**After brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
24	92.2233	0.3325	-0.4503	93.2504	0.0067	-0.172	1.11	1.0271	-0.3258	0.2783
26	92.5091	0.2419	-0.3678	93.437	-0.1004	0.0049	1.06	0.9279	-0.3423	0.3727
28	90.1942	0.2735	-0.8974	91.6753	-0.0769	-0.6045	1.55	1.4811	-0.3504	0.2929
121	91.6704	0.3293	-0.8063	92.4779	0.0137	-0.4493	0.94	0.8075	-0.3156	0.357
29	93.3452	0.2756	-0.6097	93.0281	-0.0404	-0.0792	0.69	-0.3171	-0.316	0.5305
123	95.3484	0.2694	-0.0078	95.8159	-0.0609	0.1735	0.60	0.4675	-0.3303	0.1813
30	91.9946	0.2992	-0.4284	93.0959	-0.0096	-0.2976	1.15	1.1013	-0.3088	0.1308
27	94.9361	0.2653	-0.1549	94.1278	-0.0259	0.2144	0.94	-0.8083	-0.2912	0.3693
25	90.9445	0.2736	-0.4545	93.4864	-0.0404	-0.3312	2.56	2.5419	-0.314	0.1233
122	92.2033	0.3439	-0.7881	93.6599	0.0477	-0.4082	1.53	1.4566	-0.2962	0.3799
mean	**92.57**	**0.28**	**-0.46**	**93.38**	**-0.04**	**-0.17**	**1.18**	**0.8032**	**-0.3216**	**0.2929**
SD	**1.71**	**0.03**	**0.28**	**1.14**	**0.04**	**0.28**	**0.59**	**0.97**	**0.02**	**0.13**

Zirconia Polished After Soaking vs After Brushing (Control) Colorimetry (Table 29)

Zirc P										
sp		**After Soaking**			**After brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
38	86.6374	-0.9485	1.8338	86.7196	-1.2606	2.3523	0.61	0.0822	-0.3121	0.5185
33	87.5102	-0.0642	0.0347	87.518	-0.4571	0.3599	0.51	0.0078	-0.3929	0.3252
31	90.0886	-0.1345	-0.4315	90.7033	-0.4525	0.0208	0.83	0.6147	-0.318	0.4523
32	88.1826	-0.4516	0.9704	88.4931	-0.7045	1.4314	0.61	0.3105	-0.2529	0.461
36	88.3475	0.1506	-0.2816	88.57	-0.1642	0.3611	0.75	0.2225	-0.3148	0.6427
39	88.5336	-0.601	1.1167	88.3277	-0.929	1.7717	0.76	-0.2059	-0.328	0.655
35	88.1246	0.0237	-0.0749	87.8771	-0.3053	0.4231	0.65	-0.2475	-0.329	0.498
34	88.3272	-0.0487	0.333	87.9791	-0.427	1.0429	0.88	-0.3481	-0.3783	0.7099
40	86.941	0.0629	-0.1563	86.9879	-0.2436	0.5451	0.77	0.0469	-0.3065	0.7014
37	87.2238	-0.1705	0.3938	87.683	-0.4639	1.0035	0.82	0.4592	-0.2934	0.6097
mean	**88.08**	**-0.22**	**0.37**	**88.13**	**-0.55**	**0.92**	**0.71**	**0.0536**	**-0.33**	**0.5515**
SD	**1.01**	**0.37**	**0.77**	**1.16**	**0.36**	**0.78**	**0.12**	**0.30**	**0.04**	**0.13**

Telio After Soaking vs After Brushing (Control) Colorimetry
(Table 30)

Telio										
sp		**After Soaking**			**After brushing**					
	L*	a*	b*	L*	a*	b*	**Delta E**	**Delta L**	**Delta a**	**Delta b**
20	74.1867	11.6462	30.8663	74.7372	9.2741	32.0874	2.72	0.5505	-2.3721	1.2211
11	75.0116	12.0075	31.8622	76.0542	9.3867	32.7163	2.95	1.0426	-2.6208	0.8541
15	75.1295	11.7856	31.599	75.6987	9.2504	32.5898	2.78	0.5692	-2.5352	0.9908
13	74.9908	12.8797	32.697	75.9699	10.2123	33.6133	2.99	0.9791	-2.6674	0.9163
14	75.2631	12.5233	32.2713	76.1673	9.9721	33.2787	2.89	0.9042	-2.5512	1.0074
16	75.6163	11.8737	30.9604	75.891	9.5931	32.7856	2.93	0.2747	-2.2806	1.8252
12	79.0125	12.5796	36.0839	80.0112	9.6643	37.0046	3.22	0.9987	-2.9153	0.9207
17	74.6053	11.3731	30.8979	75.3398	8.8265	31.7938	2.80	0.7345	-2.5466	0.8959
18	74.8278	11.572	31.433	75.0849	8.8212	31.5259	2.76	0.2571	-2.7508	0.0929
19	73.4725	12.0879	30.4523	74.2257	9.6146	31.36	2.74	0.7532	-2.4733	0.9077
mean	**75.21**	**12.03**	**31.91**	**75.92**	**9.46**	**32.88**	**2.88**	**0.7063**	**-2.5713**	**0.9632**
SD	**1.46**	**0.49**	**1.62**	**1.57**	**0.45**	**1.63**	**0.15**	**0.29**	**0.18**	**0.42**

Colorimetry Mean ΔE Values (SD)
(Table 31)

	ΔE (Baseline-Post-Smoking)	ΔE Post-Smoking-Post-Brushing)	ΔE (Baseline-Post-Brushing)
emax G vs control	18.8 (5.8) vs 1.3 (0.3)	18. 6 (6.2) vs 1.2 (0.1)	2.5 (0.4) vs 0.7 (0.3)
p-value	<0.001	<0.001	<0.001
emax P vs control	19.2 (4.8) vs 1.6 (0.8)	20.3 (4.4) vs 1.2 (0.1)	5.3 (3.8) vs 1.4 (0.9)
p-value	<0.001	<0.001	0.01
Zirconia G vs control	18.5 (3.8) vs 4.6 (1.6)	16.5 (6.3) vs 1.2 (0.6)	7.9 (3.2) vs 3.6 (1.0)
p-value	<0.001	<0.001	0.002
Zirconia P vs control	16.8 (2.6) vs 4.5 (1.1)	13.7 (3.9) vs 0.7 (0.1)	9.6 (1.8) vs 4.3 (1.1)
p-value	<0.001	<0.001	<0.001
Telio vs control	12.8 (5.2) vs 5.0 (1.0)	14.9 (5.0) vs 2.9 (0.2)	8.7 (2.4) vs 3.9 (1.7)
p-value	<0.001	<0.001	<0.001

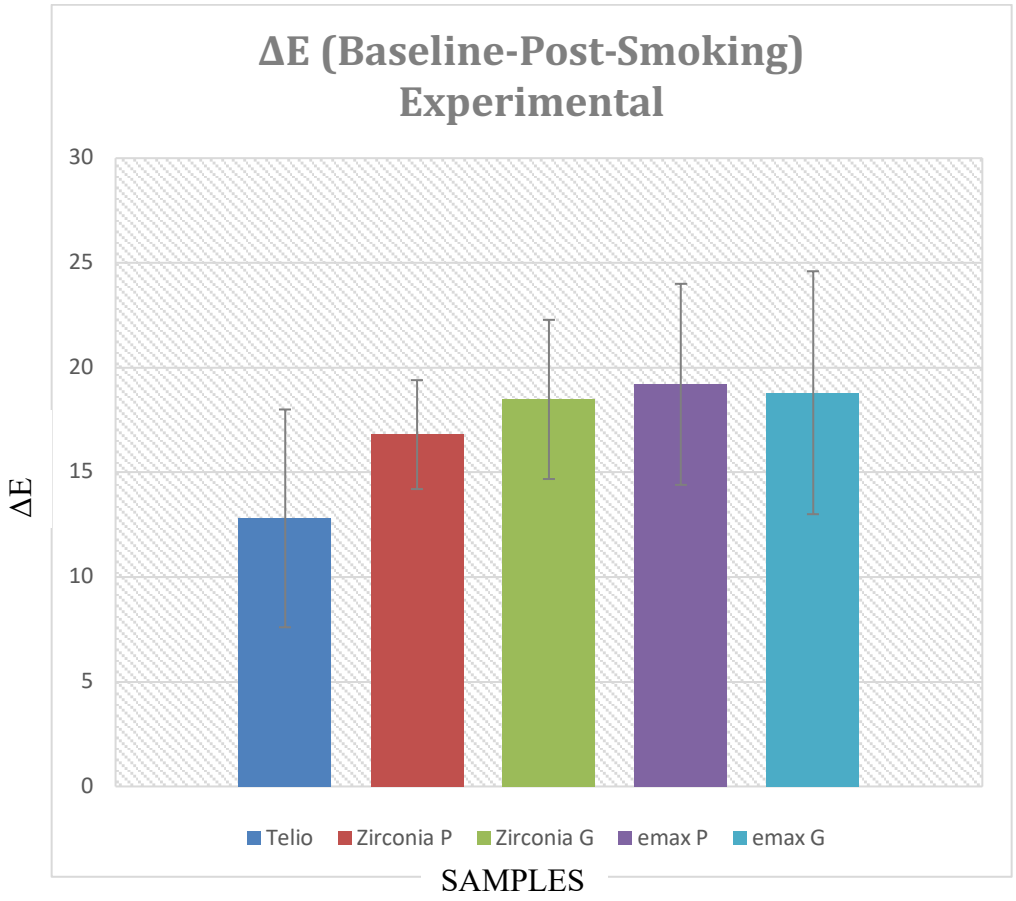

Figure 1. Color change of all test samples from baseline to post-smoking.

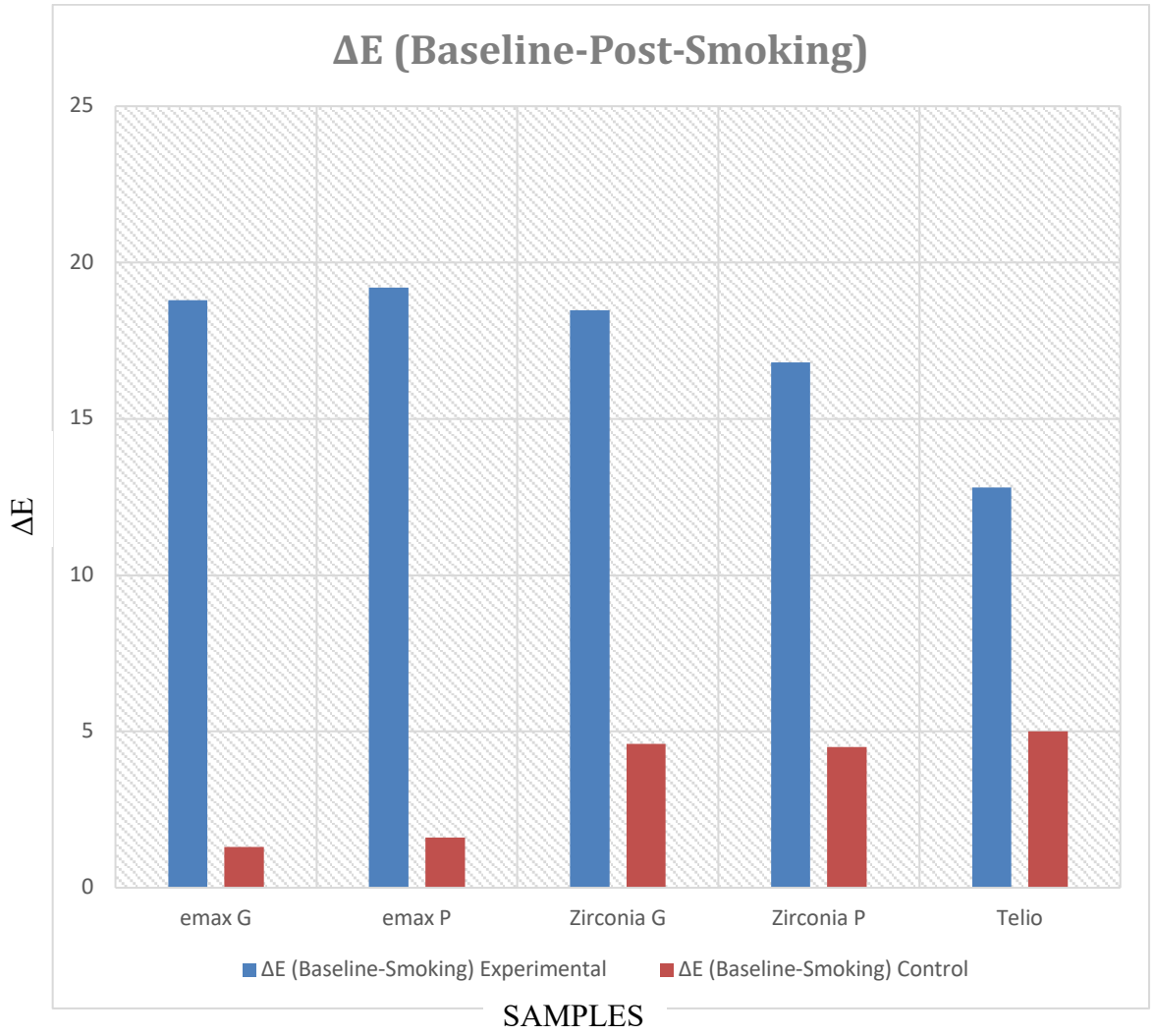

Figure 2. Color change of test and control samples from baseline to post-smoking.

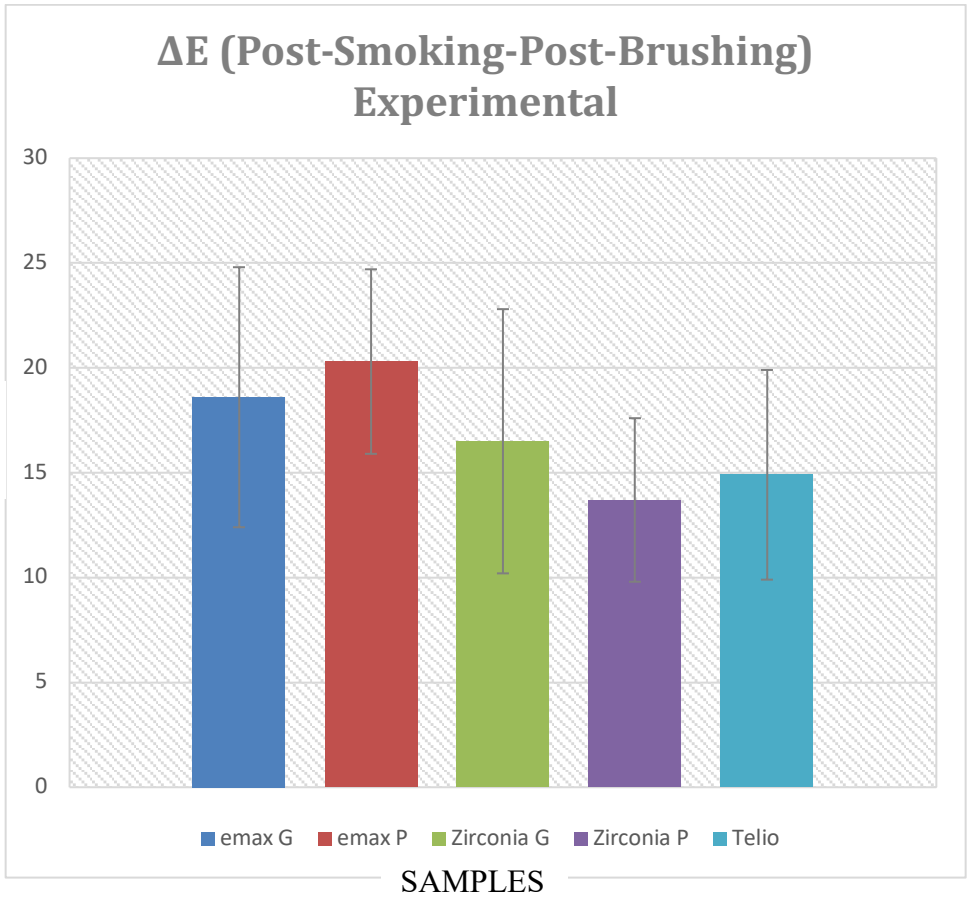

Figure 3. Color change of all test samples from post-smoking to post-brushing.

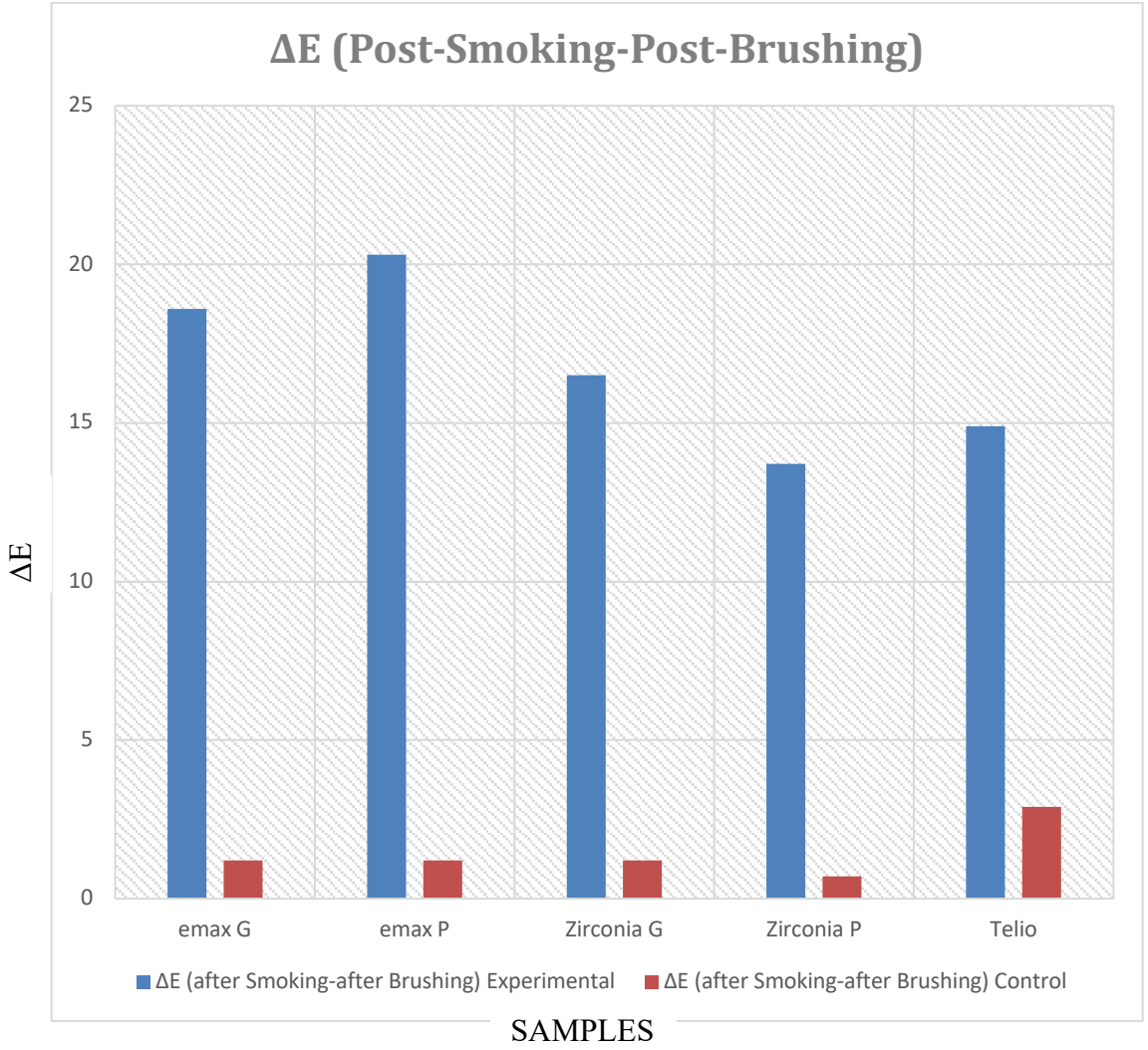

Figure 4. Color change of all test and control samples from post-smoking to post-brushing.

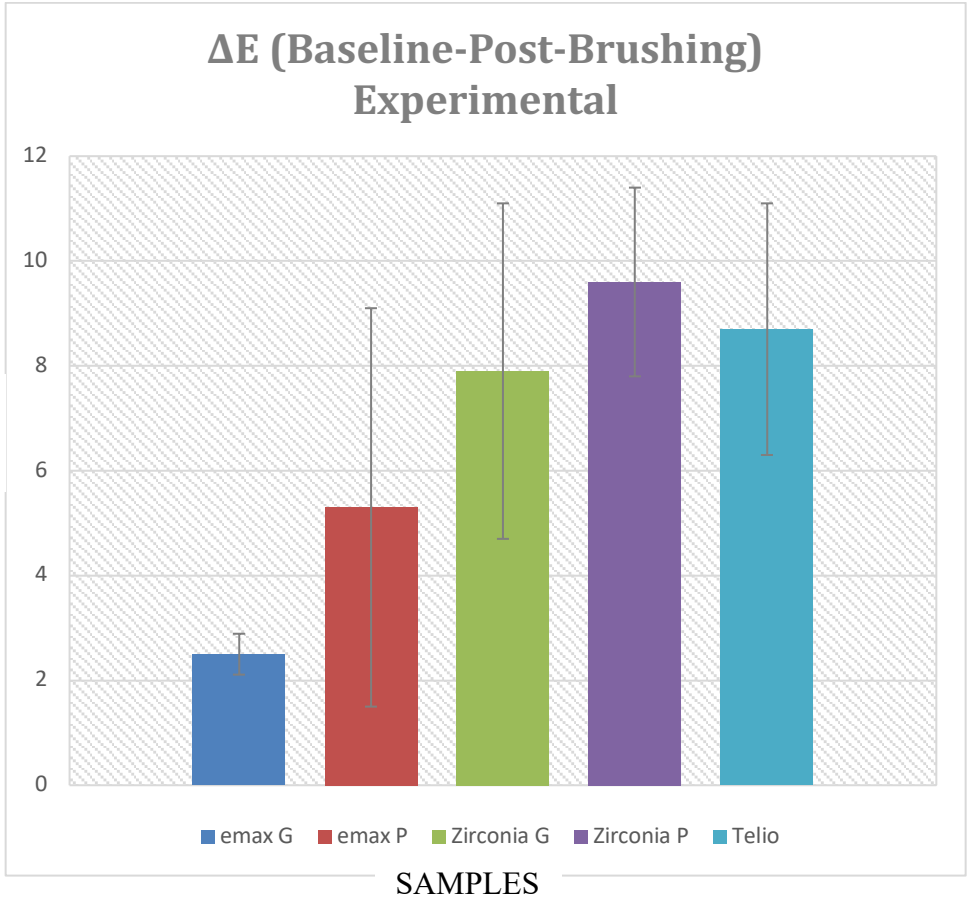

Figure 5. Color change of all test samples from baseline to post-brushing.

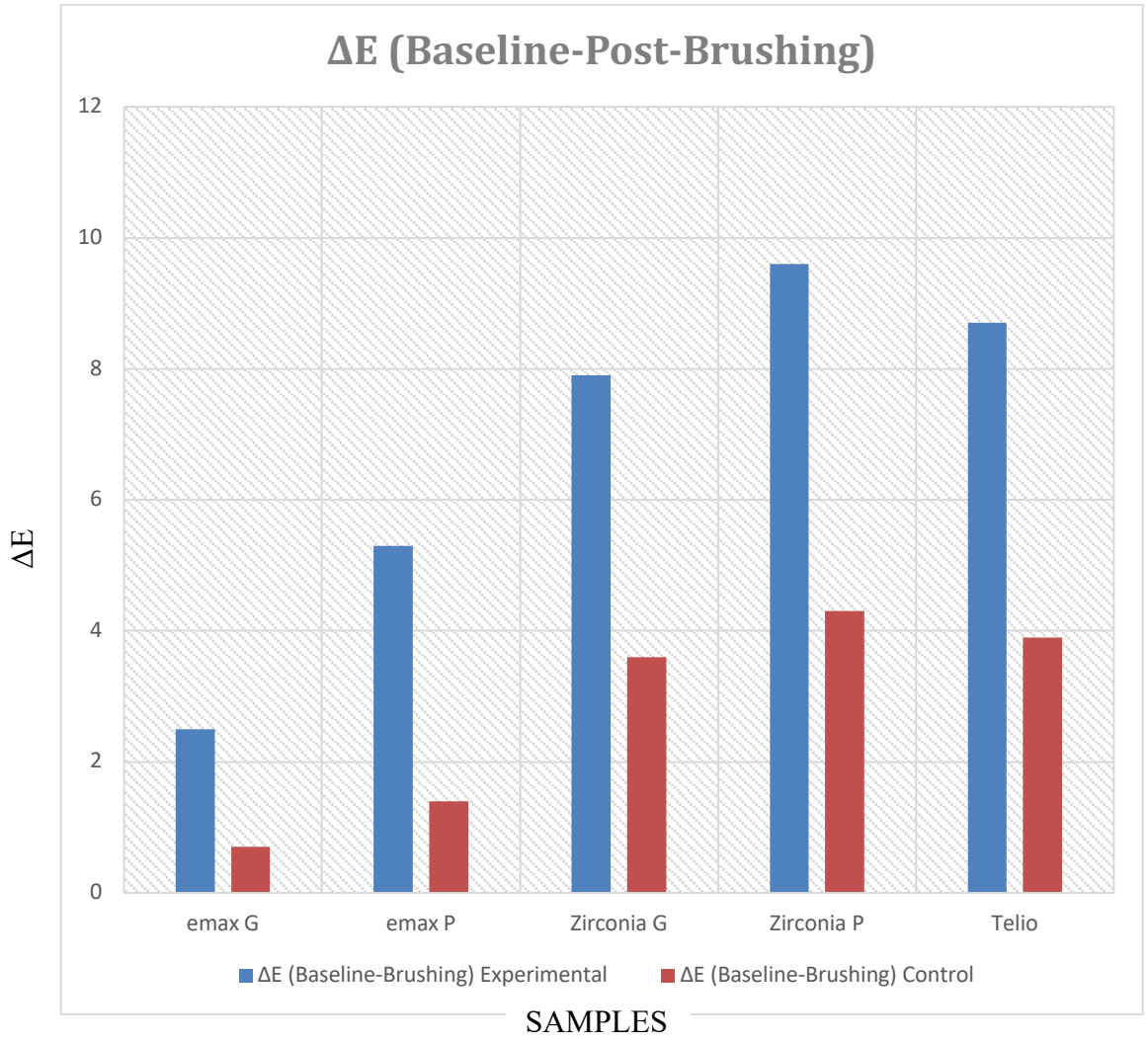

Figure 6. Color change of all test and control samples from baseline to post-brushing.

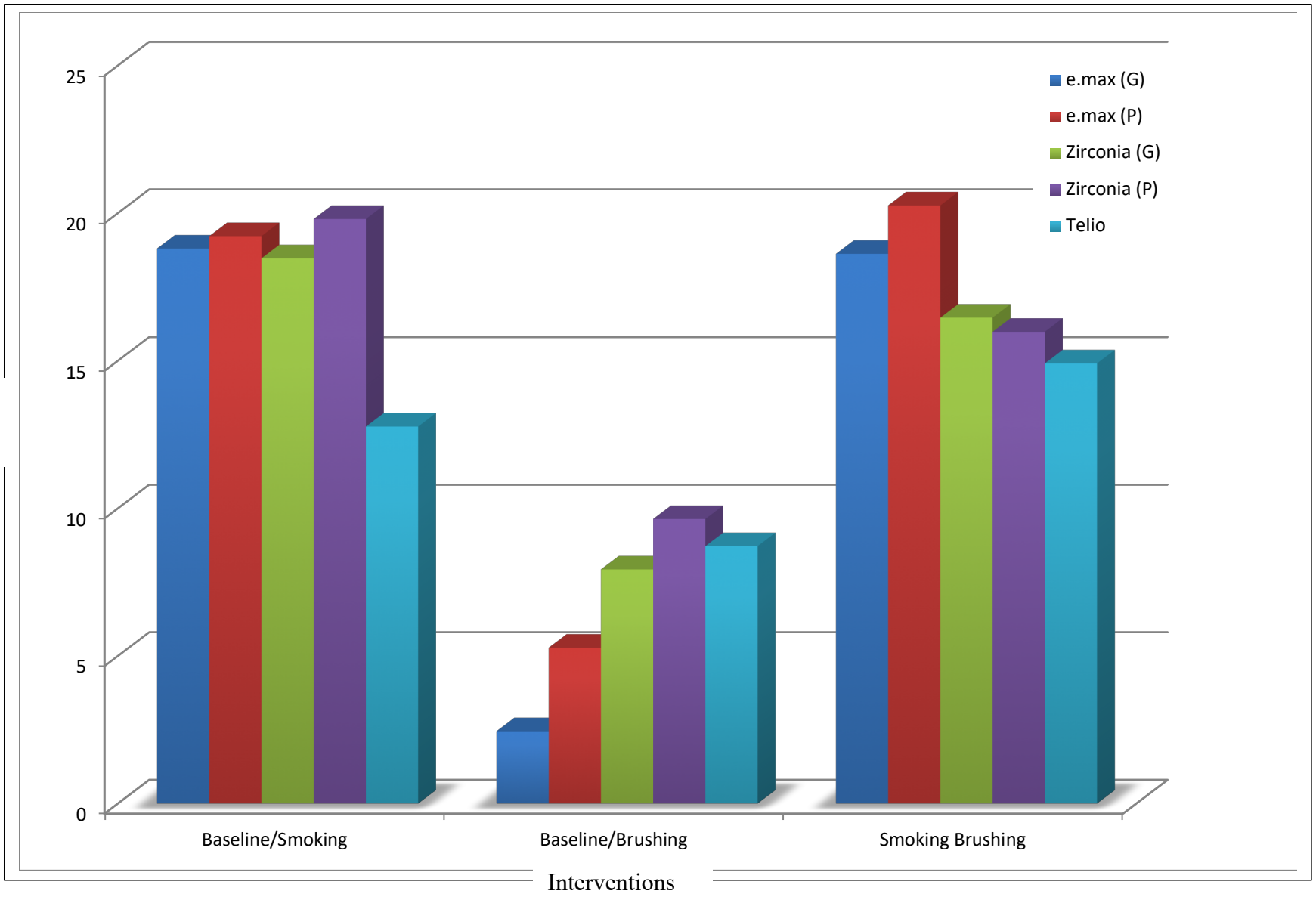

Figure 7 Color change of all test samples across all interventions.

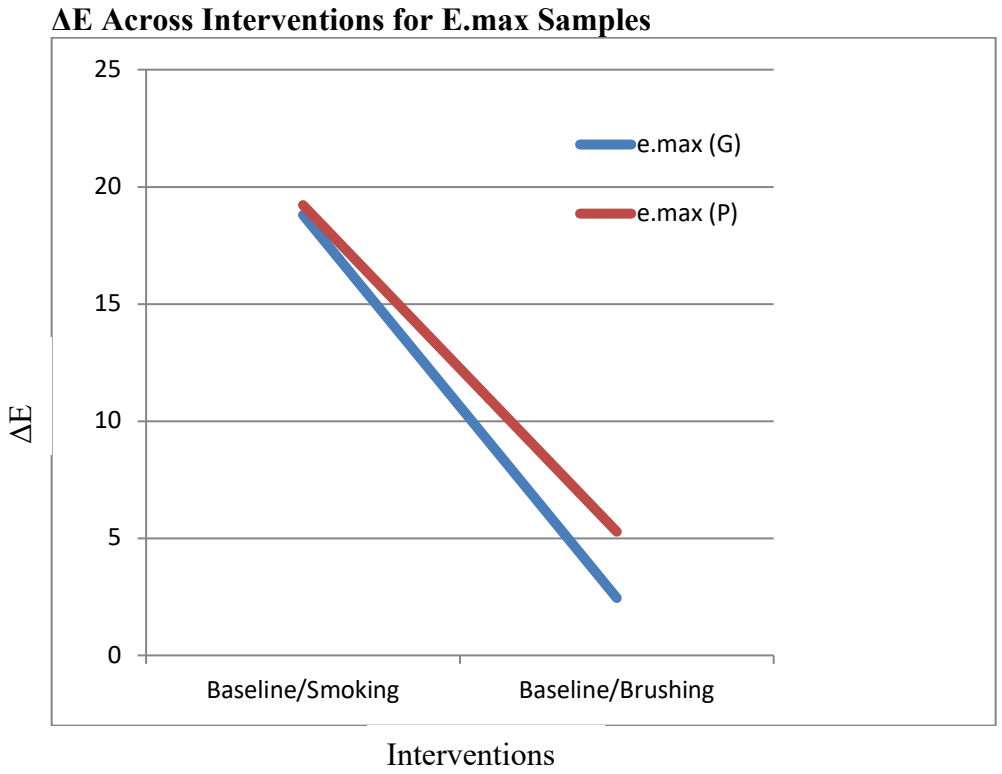

Figure 8. Color change of e.max samples from baseline to post-smoking and post-brushing.

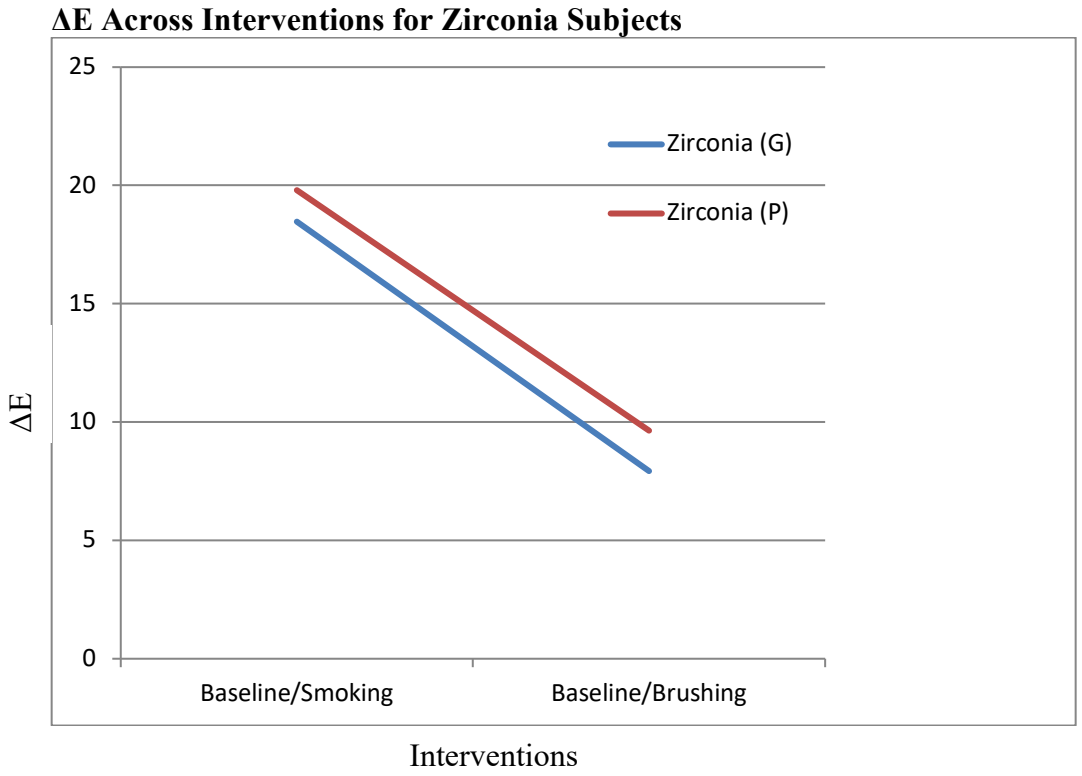

Figure 9. Color change of zirconia samples from baseline to post-smoking and post-brushing.

9. CURRICULUM VITAE

Stuart Schelkopf

Permanent address: 623 Joanne Ln, Dekalb, Illinois, USA, 60115

Mobile: 815-757-5253
Email: sschelk2@gmail.com

EDUCATION

2014 - present	The University of Illinois at Chicago, College of Dentistry, MS
2017 - 2018	The University of Illinois at Chicago, Postdoctoral Fellow – Digital Implant Fellowship
2014 - 2017	The University of Illinois at Chicago Post-Graduate Residency, Advanced Specialty Education in Prosthodontics
2010 - 2014	The University of Illinois at Chicago, College of Dentistry, DDS, May 2014 Graduating GPA: 3.97/4.00
2006 - 2010	The University of Illinois at Champaign-Urbana, BS Chemistry, May 2010 Graduating GPA: 3.95/4.00

HONORS AND AWARDS

2014	Salutatorian – UIC College of Dentistry Class of 2014
2014	Omicron Kappa Upsilon Dental Honor Society – Sigma Chapter
2014	International Congress of Oral Implantologists Pre-doctoral Student Achievement Award
2014	Academy of Osseointegration Award
2014	Academy of Dental Materials Award
2014	Delta Sigma Delta Academic Achievement Award
2014	Illinois State Dental Society Clinical and Behavioral Science Research Award
2010	University of Illinois at Champaign-Urbana University Honors/Bronze Tablet
2010	Magna Cum Laude
2010	Phi Beta Kappa Honor Society
2010	Peter C. and Gretchen Miller Markunas Scholarship
2009 - 2010	Robert Doremus Chemistry Scholarship
2009	James R. Beck Memorial Scholarship
2006 - 2010	Edmund J. James Scholar
2006 - 2010	University of Illinois at Champaign-Urbana Dean's List
2006 - 2007	Illinois General Assembly Scholarship

RESEARCH EXPERIENCE

2014 – present	University of Illinois at Chicago, Post Graduate Prosthodontics, Dr. Cortino Sukotjo, DDS, MS
2013 - 2013	University of Illinois at Chicago, College of Dentistry, Dr. Fatemeh Afshari, DMD, MS
2012 - 2013	University of Illinois at Chicago, College of Dentistry, Dr. Ana Bedran-Russo, DDS, MS, PhD

2007 - 2010 University of Illinois at Champaign-Urbana, Department of Chemistry, Dr. Jeffrey S. Moore, PhD

PUBLICATIONS/ABSTRACTS

Afshari, F.; Schelkopf, S.; Yuan, J. C.; Marinis, A.; Syros, G.; Campbell, S.; Sukotjo, C. "Patient Recall in U.S. Predoctoral Dental Education: Current Status and Perceptions," *J. of Dental Education.* 2014. DOI:

Caruso, M. M.; Blaiszik, B. J.; Jin, H.; Schelkopf, S. R.; Stradley, D. S.; Sottos, N. R.; White, S. R.; Moore, J. S. "Robust, Double-Walled Microcapsules for Self-Healing Polymeric Materials," *ACS Appl. Mater. Interfaces* 2010, *2*, 1195-1199. DOI: 10.1021/am100084k

Caruso, M. M.; Schelkopf, S. R.; Jackson, A. C.; Landry, A. M.; Braun, P. V.; Moore, J. S. "Microcapsules Containing Suspensions of Carbon Nanotubes," *J. Mater. Chem.* 2009, *19*, 6093-6096. DOI: 10.1039/b910673a

Wilson, G.O.; Caruso, M.M; Schelkopf, S. R.; Sottos, N.R.; White, S.R.; Moore, J.S. "Adhesion-Promotion via Non-Covalent Interactions in Self-Healing Polymers," *ACS Appl. Mater. Inter.* 2011, *3*, 3072-3077. DOI: 10.1021/am200584z

CaseCAT Presentation

Schelkopf, Stuart (2013). "The Prognosis of Esthetic Restorative Dental Treatment vs. Orthodontic Treatment In Adults With Malocclusion." University of Illinois at Chicago, College of Dentistry Clinic and Research Day; Chicago, IL.

CaseCAT Presentation

Schelkopf, Stuart (2014). "Patient Recall in U.S. Predoctoral Dental Education: Current Status and Perceptions." University of Illinois at Chicago, College of Dentistry Clinic and Research Day; Chicago, IL.

Poster Presentation

Schelkopf, Stuart (2017). "A Predictable, Controlled Approach to Immediate Implant-Supported Fixed Complete Dentures." 2017 AAFP Annual Session; Chicago, IL.

Schelkopf, Stuart (2017). "A Predictable, Controlled Approach to Immediate Implant-Supported Fixed Complete Dentures." 2017 APS Annual Session; Chicago, IL.

Schelkopf, Stuart (2016). "The Effects of Cigarette Smoking on the Shade of CAD/CAM Restorations." 2016 ACP Annual Session; San Diego, CA.

Schelkopf, Stuart (2015). "Full-Mouth Restoration of a Patient Presenting with Compromised Restorative Space." 2015 ACP Annual Session; Orlando, FL.

Schelkopf, Stuart (2014). "Patient Recall in U.S. Predoctoral Dental Education: Current Status and Perceptions." 2014 UIC COD Clinic and Research Day; Chicago, IL.

Schelkopf, Stuart (2013). "Patient Recall in U.S. Predoctoral Dental Education: Current Status and Perceptions." 2013 ACP Annual Session; Las Vegas, NV.

Schelkopf, Stuart (2009). "Microcapsules Containing Suspensions of Carbon Nanotubes." University of Illinois at Champaign-Urbana, Undergraduate Research Symposium; Champaign, IL

Undergraduate Senior Thesis
Schelkopf, Stuart (2010). "The Application of Self-Healing Polymerization to Conductive Materials and the Improvement of Stability of Microcapsules Through the Addition of a Second Shell Wall." University of Illinois at Champaign-Urbana, Jeffrey S. Moore Research Group; Champaign, IL.

WORK EXPERIENCE

2017 - present	Prosthodontist, Winnetka Dental Group
2017 - present	Prosthodontist, University Associates in Dentistry
2007 - 2010	Orthodontic Assistant, Curtis Orthodontics

COMMUNITY SERVICE

2010 - 2014	Volunteer, Goldie's Place
2012 - 2013	Volunteer, CommunityHealth
2012	Volunteer, TeamSmile
2011 - 2012	Volunteer, Ronald McDonald House
2010 - 2012	Volunteer, Centro de Salud Esperanza

INSTITUTIONAL SERVICE

2014 – 2017	Class Representative, UIC Post Graduate Prosthodontics Class of 2017
2012 - 2014	Treasurer, UIC College of Dentistry Class of 2014 Executive Board
2012 - 2014	Student Orthodontic Liaison, UIC College of Dentistry Rembrandt Clinic
2012 – 2013	Treasurer, UIC Hispanic Student Dental Association
2012 - 2013	UIC College of Dentistry HSDA Spanish Class Instructor
2012 - 2013	CRDTS D3 Student Liaison, UIC College of Dentistry Rembrandt Clinic
2011 - 2012	Social Chair, UIC Hispanic Student Dental Association
2010 - 2012	Social Chair, UIC College of Dentistry Class of 2014 Executive Board

MEMBERSHIPS

2013 - present	American College of Prosthodontists, Illinois State Dental Society
2010 - present	Chicago Dental Society, Delta Sigma Delta Dental Fraternity, Illinois Academy of General Dentistry
2013 – 2014	Advanced Pre-doctoral Implant Program
2010 – 2014	American Student Dental Association, Hispanic Student Dental Association