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The Effect of IDS CAD White Plus Solution on the ΔE Value of Zirconia in Representative Restorative Applications

by

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Thesis submitted to the Faculty of the
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ABSTRACT

The Effect of IDS CAD White Plus Solution on the ΔE Value of Zirconia in Representative Restorative Applications

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Statement of Problem. Zirconia is increasingly favored as a restorative material of choice for crowns because of its combination of strength and esthetic appearance. Matching the shade of the crown to the shade of the patient's natural dentition is a key requirement for the success of full coverage restorations, including those made of zirconia, and is a frequent challenge faced clinically. In addition to their color properties, teeth have varying degrees of translucency, and in order to look natural, crowns must also incorporate a certain amount of translucency. However, this can permit the dark underlying abutment to show through and alter the tooth shade. IDS CAD White Plus (IDS CAD, Centreville, VA) solution has been developed as a solution for this problem as it relates to zirconia crowns. Knowledge of the effectiveness of IDS CAD White Plus solution could be used to improve the esthetic outcome of zirconia full coverage restorations for patients.

Purpose. The purpose of this study is to investigate the effect of IDS CAD's White Plus solution on the final shade of varying brands and thicknesses of zirconia.

Material and Methods. Wafers of varying thicknesses (0.70 and 1.00 mm), were fabricated out of two different brands of zirconia, Katana HT (Kuraray Noritake, Tokyo, Japan) and ZirCAD MO (Ivoclar Vivadent, Schaan, Liechtenstein). IDS CAD White Plus solution was applied to half of the samples prior to sintering to create the opaque layer. A dental spectrophotometer, the Vita Easyshade 4.0 (Vita Zahnfabrik, Bad Sackingen, Germany) was used to measure the ΔE of the zirconia wafers as they were placed over darker stumpfs (a titanium disc to represent implant abutments and a resin block in stumpf shade "ND8" to represent a dark tooth substrate), to determine the effect of the IDS CAD White Plus solution on the change in color of the wafer. A 3-way ANOVA was performed to determine interactions between the brand, thickness, and if the wafer received the opaque treatment, for both the ND8 and Titanium stumpfs.

Results. Overall the ΔE Value of the zirconia wafers was reduced with the application of the IDS CAD White Plus solution in a statistically significant manner. The mean ΔE values of the untreated wafers over the ND8 stumpf were 1.60 (ZirCAD 1mm), 1.63 (ZirCAD 0.7mm), 1.39 (Katana 1mm), and 1.45 (Katana 0.7mm). The mean ΔE values for wafers treated with White Plus solution over the ND8 stumpf were 0.81 (ZirCAD 1mm), 0.97 (ZirCAD 0.7mm), 0.69 (Katana 1mm), and 0.92 (Katana 0.7mm). The mean ΔE values of the untreated wafers over the titanium stumpf were 0.69 (ZirCAD 1mm), 0.85 (ZirCAD 0.7mm), 0.65 (Katana 1mm), and 0.78 (Katana 0.7mm). The mean ΔE values for wafers treated with White Plus solution over the titanium stumpf were 0.39 (ZirCAD 1mm), 0.47 (ZirCAD 0.7mm), 0.43 (Katana 1mm), and 0.42 (Katana 0.7mm). 3-way ANOVA showed no statistically significant three-way interaction ($p<0.05$) between application of the White Plus, brand of zirconia, and thickness of zirconia for either the ND8 or titanium stumpf, but there were statistically significant two way interactions between the brand and application of solution, as well as between solution and thickness for the ND8 stumpf. There were no statistically significant two way interactions for the titanium stumpf.

Conclusions. The application of the IDS CAD White Plus solution did function as intended to opaque the zirconia and reduce the ΔE value of the zirconia over both the ND8 and the Titanium stumpf. However, none of the ΔE values calculated were above the minimum ΔE required to be perceptible to the human eye (2.6 from our literature review), or the minimum ΔE found to be clinically unacceptable (3.7 from our literature review).

CLINICAL RELEVANCE

Because all of the ΔE values calculated were below the average perceptibility and acceptability thresholds, there is no clinical significance.

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CHAPTER 1: INTRODUCTION

STATEMENT OF THE PROBLEM

Crowns are a frequently used restoration for the human dentition, and they serve to restore the outer surfaces and contours of a tooth or an implant abutment. Zirconia is increasingly favored as a restorative material of choice for crowns because of its combination of strength and esthetic appearance. Matching the shade of the crown to the shade of the patient's natural dentition is a key requirement for an esthetically pleasing smile that is being restored with full coverage restorations, including those made of zirconia. Tooth and crown color matching is based on the properties of value, chroma, and hue. The difference in tooth shade is measured objectively by a calculation that finds ΔE. Numerous research studies have been done to establish average values for the ΔE as it relates to perceptibility as well as acceptability of the final esthetics of the restoration. Unmatched tooth shade creates an esthetic problem and if the ΔE is over 3.7 that crown is typically deemed unacceptable and has to be remade.

In addition to color properties, teeth have a varying degree of translucency. Therefore, in order for the crown to look natural, translucency must also be incorporated into the crown appearance. However, due to the translucency of the zirconia crown material, the dark underlying tooth shade or the titanium implant abutment can show through to some degree. Frequently for a full and accurate match of the color of a final restoration to the patient's natural dentition, the dark color of the tooth or implant substrate underneath must be blocked out. IDS CAD White Plus Solution has been developed as answer for this problem. The solution is applied to the inside surface of the crown during the fabrication process and aims to change the way the dark underlying color transmits through the crown and therefore the perceptibly and acceptability of the final color scheme.

Knowledge of the effectiveness of IDS CAD White Plus solution could be used to improve the esthetic outcome of zirconia full coverage restorations for patients. Zirconia crowns are currently used extensively as a restorative material of choice at Tingay Dental Clinic and IDS CAD's solution is routinely applied in order to block out dark substrates and improve the ΔE of the final restorations. However, the effectiveness of IDS CAD's solution as it relates to the brand of zirconia used, the thickness of the zirconia restoration, and the material of the dark underlying substrate, is unknown.

SIGNIFICANCE

If there is a difference in color perception based on the application of IDS CAD's White Plus solution to zirconia crowns in different restorative applications, such as different brands or thicknesses or zirconia, or over different substrates, such as implant abutments or dark natural teeth, then the esthetics of zirconia crowns could be improved by taking that into account during fabrication. Whether or not the shade match of a crown is acceptable is determined subjectively by both the provider and patient. If extra factors involved in shade selection of zirconia crowns can be accounted for and controlled, the resulting crowns will have fewer rejections and Soldiers will have to spend less time in the dental chair. By achieving fewer crown remakes the US Army will also save time and money.

CHAPTER 2: REVIEW OF THE LITERATURE

INTRODUCTION

When restoring human dentition that has been lost or damaged, either from trauma or dental caries, it is easy to judge the success of the restorations replacing the original teeth based on their functionality. We can replicate the size and shape of the previous dentition with our replacements and fabricate them in such a way so as to restore the patient's masticatory function. However, the true challenge lies in the restoration of the esthetics of the original dentition. This is a much harder metric in which to judge success. Furthermore, the success of the esthetics of a restoration is determined not only by the dentist, but also by the patient, their friends and family, and ultimately anyone who will be able to see the patient's restoration.

While the shape and contour of restorations certainly affect the overall esthetics, the most challenging aspect is matching the shade of a ceramic restoration to the neighboring dentition. The challenge of shade matching is attributed mainly to the complex optical characteristics of natural teeth.[1] Current studies suggest that nearly half of all ceramic crowns produced have a shade mismatch.[2,3] Shade matching is considered to be a key requirement when determining the success of prosthodontic restorations.[4] This is especially true if a shade mismatch results in patient dissatisfaction or necessitates that the restoration be remade.

COLOR THEORY

For a dentist to accurately match the shade of a patient's dentition, a working knowledge of the science behind color and light and how it relates to dental materials is essential. Sir Isaac Newton was the first to discover that light could be broken down into different wavelengths, which he noted while observing white light as it passed through a prism. The spectrum of colors that are visible to the human eye actually consist of only a narrow band of wavelengths out of the total spectrum of wavelengths of light that exist. The wavelengths of this visible spectrum range only from 400nm to 700nm, with ultraviolet light below 400nm and infrared light above 700nm marking the beginnings of the invisible spectrum. When light strikes or passes through an object, some of the light is absorbed by the object. A perfectly white object will reflect all wavelengths of light while a perfectly black object will absorb all wavelengths. The wavelengths that are not absorbed get reflected, and those reflected wavelengths are detected by the receptor cells in the eye (rods and cones). The brain recognizes the specific colors associated with the wavelengths it is detecting and the sum effect is that an object is perceived to be a color that is actually a composition of all the wavelengths that it reflects.[5]

In 1905, an art professor named Albert Munsell published a new system for accurately describing and communicating color. His system has become the foundation of our modern understanding of color. In his system, color is defined as having three components or dimensions; hue, value, and chroma (Figure 1). Hue is the color's tone, such as red, blue, or green. This is determined by the aforementioned wavelengths. Value is the relative lightness or darkness of the color, i.e. the amount of white or black mixed in with the color. Chroma is the relative purity or intensity of the color, such as a bright blue versus a faded blue.[5] An understanding of his three dimensional concept and how the different dimensions relate to each other is essential for describing and selecting shades to match the human dentition.

TRANSLUCENCY

Atlhough an understanding of Munsell's three dimensional model forms the basis for shade matching in the human dentition, there is yet another dimension that needs to be taken into consideration. That dimension is translucency, which is the degree to which light is transmitted through a material, rather than absorbed or reflected. A completely transparent object would permit all light to transmit through, whereas a completely opaque object would not permit any light to be transmitted. In their book "Fundamentals of Color," Chu et al consider translucency to be the fourth critical dimension for successful shade matching.[6] Natural human teeth possess the characteristic of translucency, both in the outer enamel layer and inner dentin layer, which makes it a critical factor to consider when fabricating an esthetic dental prosthesis that matches and mimics the natural dentition.[7,8]

Furthermore, if a dental prosthesis is fabricated with sufficient translucency to accurately mimic the natural dentition, another aspect that comes in to play is the substructure on which the prosthesis is placed. Very frequently the substructure or abutment for the restoration is dark or opaque, such as in the case of an implant supported crown placed over a titanium abutment or even a lightly colored crown placed over a darker natural tooth. When light transmits through a translucent restoration and hits the surface of an opaque abutment, it will summarily be reflected, scattered, and absorbed to varying degrees depending on the properties of that abutment. In the case of an opaque implant abutment the light that is absorbed and reflected has already passed through the translucent ceramic crown that also partially absorbs and reflects a portion of that light. This results in a complex interaction of light and color transmission properties that contributes to a range of wavelengths leaving the surface of the tooth, which can alter the perceptions of all four dimensions of the color of the prosthesis.[7,8]

COLOR MEASUREMENT

All four dimensions of color need to be accurately assessed when selecting the color or shade of a dental prosthesis. Currently there are different methods available for selecting the shade, including visual assessment or instrumental assessment. Traditionally, the visual method for ascertaining the color or shade of the dentition has been the method employed by dentists, frequently through the use of a shade guide. This method is highly subjective and based on the individual's ability to accurately compare and match the shade of the natural teeth to the guide. An array of variables can lead to this method being inconsistent and inaccurate, including environmental variables, such as lighting conditions and time of day. In addition, physiologic variables such as the skill or even age of the individual doing the shade selection may also affect the outcome.[9] These variables can result in the wrong shade being selected. In a shade selection study where three dentists were asked to select the shade for a dental restoration using a traditional shade guide, in 86% of the cases the three dentists could not agree on the shade, thus illustrating the subjectivity of the traditional visual method.[10]

Due to the subjectivity and unreliability of the visual method, newer methods were developed that use instruments to assess the color through quantifiable data, and these have proven to be more accurate and reliable when compared to the conventional visual method.[10-11] Instrumental analysis of color has made significant advances in the last twenty years.[12] The instruments that are used can be divided into two different types based on differing methodologies. These different categories are spectrophotometers and colorimeters. Spectrophotometers measure the wavelengths of light reflected from an object and record a quantifiable measurement of the value, chroma, and hue of the light being reflected, as measured across the entire spectrum of visible light. The Vita Easyshade (Vita Zahnfabrik, Bad Sackingen, Germany) and the MHT SpectroShade (Medical High Technologies, Verona, Italy) are examples of spectrophotometers. Colorimeters, on the other hand, measure color by filtering light in only three or four areas of the visible spectrum to determine the color of an object. The X-Rite ShadeVision (X-Rite, Grand Rapids, Michigan) is an example of a colorimeter. A 2009 study by Kim-Pusateri et al compared the reliability and accuracy of these different varieties of shade matching instruments and found that the VITA Easyshade spectrophotometer was the only color measurement instrument tested that had both reliability and accuracy values greater than 90%.[13] Another study by Kalantari et al in 2017, found spectrophotometric instruments to be significantly more accurate than the traditional method and found the Vita Easyshade to be more accurate when compared to the visual method in 85% of instances employed.[14]

QUANTIFICATION OF DIFFERENCES IN COLOR

The International Commission on Illumination developed a system in 1976 for objectively measuring the color difference between two subjects.[15] The metric produced is referred to as the ΔE value, with E representing the German word *Empfindung*, which means "sensation." The color difference (ΔE) between two objects can be determined objectively by measuring the difference between respective coordinate values of brightness (L), value of red or green chroma (a), and value of yellow or blue chroma (b). The resulting calculation, L*a*b* is referred to as CIELAB and is calculated:

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

where ΔL*, Δa*, and Δb* are the differences in lightness, green-red coordinate and blue-yellow coordinate, respectively.[15,16] The calculation was further refined in 2004 to account for hue rotation and also to include compensation for neutral colors, lightness, chroma, and hue.[17] Hue rotation is a function added to weight the interaction between chroma and hue differences. Compensation for neutral colors, lightness, chroma, and hue were necessary to deal with perceptually uniformity, which is when two different colors are so close together as to be indistinguishable. This refined calculation is known as CIEDE2000 and is calculated:

$$\Delta E' = \left[\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)\right]^{1/2}$$

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ are the differences in lightness, chroma, and hue for the pair of samples, and R_T is the hue rotation function.[17] The weighting functions, S_L, S_C, S_H and the parametric factors, K_L, K_C, K_H, were introduced into the calculation in order to allow for differences in texture, background, separations, etc for the lightness, chroma and hue components, respectively.[17] Ghinea found that the CIEDE2000 color difference formula provided a better fit than CIELAB formula in the evaluation of color difference thresholds of dental ceramics.[18] Gomez-Polo et al found that the CIEDE2000 formula reflects the color differences perceived by the human eye better than the CIELAB formula and should be the preferred formula for measuring color differences for clinical interpretation.[19] Other research by Wee et al in 2007 also supported the use of the CIEDE2000 color difference formula as it provided a better fit to the calculated color differences, and is therefore better indicators of human perceptibility and acceptability of color differences between tooth colors.[20]

PERCEPTION OF COLOR

An understanding of color differences and how to objectively measure and calculate those differences is a significant topic for dentistry and dental research. Specifically, the research has looked to establish accepted thresholds relating to our ability to perceive a difference in color as well as what difference we are willing to accept in a dental prosthesis. The smallest color difference that can be detected by 50% of observers is referred to as the 50:50% perceptibility threshold. The difference in color that is acceptable for 50% of observers (i.e. not requiring a dental prosthesis to be remade or replaced due to the color mismatch) is referred to as the 50:50% acceptability threshold.[4,11] Thus far, a consensus has not been reached for established values for the perceptibility and acceptability thresholds in clinical dentistry.[11] Acceptability and perceptibility tolerance thresholds of shade mismatch determined in a clinical setting were found to be considerably higher than those previously determined under nonclinical conditions. Douglas et al. in 2007 recommended that future dental investigators evaluating color differences should compare the results to perceptibility and/or acceptability tolerance levels that have been determined under clinical conditions.[15]

In large part, it is so challenging to establish accepted values for these thresholds because they are so subjective, and research into the topic has produced varying results. A 1989 study in the Journal of Dental Research by Johnston et al established the clinical threshold for an acceptable shade match to be 3.7 ΔE units or less.[21] A systematic review by Khashayar et al. in 2013 found that over a third of the studies they reviewed referred to a ΔE value of 3.7 as the acceptability threshold.[22] Douglas et al in 2007 reported that 50% of observers could perceive a color difference of 2.6 ΔE units, and that clinically a 5.5 ΔE unit difference in color was considered unacceptable.[15] Ragain in 2001 noted that patients are not as discriminating in their ability to identify color differences in dental prosthesis as are dental professionals.[23] According to Da Silva et al in 2008, there is no agreed upon standard for an acceptable ΔE value but their research reported that intraoral color matching could vary by as much as 3.7 ΔE and still be considered acceptable.[24] They also found that the ΔE values for crowns matched to the natural dentition with a spectrophotometer were notably lower than the values for crowns matched using the traditional visual method, and that these visually matched crowns were more likely to be found unacceptable.

ZIRCONIA RESTORATIONS

In modern dentistry, all-ceramic materials have become the most commonly used for esthetic restorations, and they are now the material of choice.[25] They have become increasingly popular as an alternative to the more traditional metal ceramic restorations because of their excellent aesthetics, chemical stability and biocompatibility. All-ceramic materials continue to evolve as more research is done, and this evolution of advanced dental ceramics has led to the application of partially stabilized zirconia in restorative dentistry which can be now produced using CAD/CAM systems. The use of zirconia-based ceramics for dental restorations has risen in popularity due to their superior fracture resistance and toughness compared with other dental ceramic systems.[26] In the US Army specifically, zirconia based restorations have become extremely popular restorations and that is why zirconia was chosen for this study. The two most commonly utilized brands of monolithic zirconia by the Army Dental Lab for fabrication of zirconia restorations were selected for the study, Katana Zirconia (HT) by Kuraray-Noritake, and IPS e.max ZirCAD (MO) by Ivoclar Vivadent.

Zirconium dioxide (ZrO2), known as zirconia, is a white crystalline oxide of zirconium. Zirconia is a polycrystalline ceramic without any glass component. Being polymorphic, three forms of zirconia exist: monoclinic, cubic and tetragonal. Pure zirconia assumes the monoclinic form at room temperature which is stable up to 1,170°C. Beyond this temperature, a transformation to the tetragonal phase occurs, which is stable up to 2,370°C, after which the cubic phase transformation is seen. A transformation of tetragonal to monoclinic occurs while cooling down to the temperature of 1,170°C. This is associated with a volume expansion of 3% to 5%.[27] The addition of dopants, such as yttrium oxide, stabilizes zirconia in its tetragonal phase at room temperature. Tensile stresses at a crack tip will cause the tetragonal phase to transform into the monoclinic phase with an associated 3-5% localized expansion. This volume increase creates compressive stresses at the crack tip that counteract the external tensile stresses and retards crack propagation. This phenomenon is known as transformation toughening.[28]

Zirconia-based restorations have become very popular due to their superior mechanical properties with flexural strength more than 1,000 MPa and excellent biocompatibility. Traditionally zirconia was a whitish opaque material that required veneering porcelain to increase translucency for esthetic dental applications.[29] In recent years the technology has advanced and we have learned how to improve the esthetic appearance and translucency of zirconia by modifications in the fabrication and sintering process.[30]

Zirconia restorations are fabricated by milling technology. They are usually made by the milling of partially sintered blocks, which are much softer and easier to mill. After milling, the restoration receives a final sintering at high temperature. This sintering procedure is accompanied by a sintering shrinkage of about 20% to 30%. The sintering cycle is divided into a heating stage, a holding stage at the final sintering temperature and a cooling stage. Alterations in this sintering cycle may be used in order to optimize the esthetic properties of zirconia such as the translucency, however this can also decrease its strength.[31]

ESTHETICS OF ZIRCONIA RESTORATIONS

In recent years, more translucent zirconia has been introduced that has an excellent combination of esthetic qualities while still retaining much of its mechanical benefits such as strength. It is manufactured either by decreasing the grain size to less than 500 nm, eliminating light scattering alumina sintering aids, or by incorporating zirconia crystals in the cubic phase. This fully stabilized zirconia in the cubic phase has been developed specifically for use in the esthetic zone. However, in this phase, the zirconia does not exhibit the aforementioned transformation toughening and so does not exhibit the superior mechanical properties of partially stabilized zirconia, i.e. that which is in both the tetragonal and the cubic phase.[32]

This high translucency zirconia is the material of choice now for esthetic cases as its translucency can closely mimic that of a natural tooth. However, because the zirconia is so translucent, the thickness of the material alone is insufficient for blocking out the darker shade of the stumpf or abutment that the restoration is placed upon.[33] For an all-ceramic crown, such as one made out of high translucency zirconia, the greater the translucency of the material, the more the colors of the deepest layers of the tooth are transmitted to the surface.[34] This can be a problem when the stumpf or abutment is of a substantially darker color or shade, such as in the case of a titanium implant abutment, or even the darkened remnants of a natural tooth. The IDS CAD White Plus solution is an entirely unique and new product in that it was developed to create an opaque layer on the intaglio surface of a zirconia crown. The mechanism is proprietary per the company, however it is applied in a thin layer to the intaglio surface prior to the final sintering of the restoration and produces an opaquing effect. Clinically it has been found to be effective at blocking out the darker stumpf shades and is currently being used routinely at the US Army Prosthodontic Residency program. This study is designed to investigate its effectiveness.

CHAPTER 3: MATERIALS AND METHODS:

The purpose of this study is to investigate the effect of IDS CAD's White Plus solution (also referred to as Chang's solution) on the final shade of a zirconia crown. This was accomplished by measuring the ΔE of zirconia wafers, Katana HT (Kuraray Noritake, Tokyo, Japan) and ZirCAD MO (Ivoclar Vivadent, Schaan, Liechtenstein), of varying thicknesses (0.7 and 1.00 mm) on stumpfs (a titanium disc to represent implant abutments and a resin block in stumpf shade "ND8" to represent a dark tooth substrate). The titanium disc was cut from a one-half inch by 12 inch titanium (Ti-6Al-4V) rod using a precision saw (IsoMet Slow Speed Saw, Buehler, Lake Bluff, IL). The wafers were designed using 3Shape CAD Software (3Shape A/S, Copenhagen, Denmark) and milled on the PrograMill PM7 (Ivoclar Vivadent, Schaan, Liechtenstein). The zirconia wafters were tested on the two different dark stumpfs to determine the effect of IDS CAD White Plus solution on the change in color of the wafer.

First, the baseline reference shade of the two different brands of zirconia wafers (Katana HT in shade A2 and ZirCAD MO in shade A2) with thicknesses of 0.7 mm and 1.0 mm was measured by placing them on a solid block of composite resin in a matching A2 shade (Radica, Dentsply Sirona, Charlotte, North Carolina) and using the spectrophotometer (Vita Easyshade 4.0, Vita Zahnfabrik, Bad Sackingen, Germany) to measure the initial shade of the wafer. The thicknesses were chosen to be representative of the minimum and average thicknesses of zirconia full coverage restorations. Once the baseline shade of the wafer was recorded, it was placed over a solid block of ND8 colored resin (IPS Natural Die Material, Ivoclar Vivodent, Schaan, Liechtenstein) and the shade of the wafer was measured again and the ΔE value (shade difference) was calculated. The test was then repeated again with the wafer placed over a solid block of titanium, and the ΔE value calculated once again.

A dental spectrophotometer (Vita Easyshade 4.0) was used for this study. This spectrophotometer has the ability to display the L*C*h* and a*b* coordinates in the CIE L*a*b* color space for the measured tooth shade. This corresponds to the physical wavelength of light. In the L*C*h* system it is represented as an angle ranging from 0° to 360°. Angles that range from 0° to 90° are reds, oranges and yellows; 90° to 180° are yellows, yellow-greens and greens; 180° to 270° are greens, cyans (blue-greens) and blues; 270° to 360° are blues, purples and magentas, returning again to red at 360° (the same as 0°). The Easyshade automatically calculates the ΔE between the two materials being tested based on these measurements.

Eighty zirconia wafers were fabricated. Forty of the wafers were Katana HT in shade A2, with twenty as 10 mm x 10 mm x 0.7 mm wafers, and twenty as 10 mm x 10 mm x 1.0 mm wafers. Forty wafers were ZirCAD MO in shade A2, with twenty as 10 mm x 10 mm x 0.7 mm wafers, and twenty as 10 mm x 10 mm x 1.0 mm wafers. Each subgroup of twenty wafers was further divided into two ten unit subgroups, with ten of the wafers receiving an application of the IDS CAD White Plus solution on one side of the wafer prior to sintering, and the other ten remaining in their original condition with no solution applied. All eighty wafers were sintered in a Mihn-Vogt HTS sintering oven (Mihm-Vogt GmbH, Stutensee, Germany). Each subgroup of ten wafers had an initial baseline shade reading by placing the wafers one at a time on a 10 mm x 10 mm x 10 mm block of A2 composite resin (Radica, Dentsply Sirona, Charlotte, North Carolina) sitting on a white background under color corrected light (Phillips 32 Watt 48" 5000K), and the entire group's shades were compared to ensure intergroup color consistency. The shade was measured with the Vita Easyshade 4.0 dental spectrophotometer. These initial readings served as the control shade and the ΔE measured the change from this baseline shade after the wafers were placed on the darker stumpfs.

The ten wafers from each subgroup were placed on a 10 mm x 10 mm x 10 mm block of ND8 colored composite resin sitting on a white background and the shade was measured with the Vita Easyshade spectrophotometer. The Easyshade calculated the ΔE value of the shade difference from the original baseline shade. Another group of ten wafers from each subgroup was placed on the 10 mm diameter solid titanium cylinder block, the shade measured, and ΔE value calculated by the spectrophotometer. Color shade differences measured in ΔE between untreated zirconia wafers and wafers treated with the IDS CAD White Plus Solution were plotted and compared using a Three-way ANOVA (IBM SPSS Software, IBM, Armonk, New York).

CHAPTER 4: RESULTS

The ΔE values for the treated and untreated zirconia wafers, over both the ND8 and titanium stumpf can be easily referenced in Table 2. The ΔE values for the untreated zirconia wafers placed over the ND8 stumpf are as follows: (Data are mean ± standard deviation unless otherwise stated) 1.0mm ZirCAD MO 1.603 ± 0.144, 0.7mm ZirCAD MO 1.627 ± 0.144, 1.0 mm Katana HT 1.39 ± 0.097, and 0.7mm Katana HT 1.45 ± 0.045. The ΔE values for the zirconia wafers treated with IDS CAD White Plus Solution placed over the ND8 stumpf are as follows: (Data are mean ± standard deviation unless otherwise stated) 1.0mm ZirCAD MO 0.810 ± 0.167, 0.7mm ZirCAD MO 0.973 ± 0.068, 1.0 mm Katana HT 0.693 ± 0.052, and 0.7mm Katana HT 0.92 ± 0.057.

The ΔE values for the untreated zirconia wafers placed over the Titanium stumpf are as follows: (Data are mean ± standard deviation unless otherwise stated) 1.0mm ZirCAD MO 0.69 ± 0.179, 0.7mm ZirCAD MO 0.847 ± 0.172, 1.0 mm Katana HT 0.65 ± 0.072, and 0.7mm Katana HT 0.78 ± 0.050. The ΔE values for the zirconia wafers treated with IDS CAD White Plus Solution placed over the Titanium stumpf are as follows: (Data are mean ± standard deviation unless otherwise stated) 1.0mm ZirCAD MO 0.393 ± 0.111, 0.7mm ZirCAD MO 0.473 ± 0.066, 1.0 mm Katana HT 0.343 ± 0.032, and 0.7mm Katana HT 0.42 ± 0.048.

A three-way ANOVA was conducted to determine the effects of IDS CAD White Plus Solution, brand of zirconia, and thickness of zirconia on the ΔE value over the ND8 stumpf. Data are mean ± standard deviation, unless otherwise stated. There were two outliers assessed as a value greater than 3 box-lengths from the edge of the box for one group (1.0 mm thick ZirCAD

MO wafers that were not treated with IDS CAD White Plus). ΔE values were normally distributed ($p > .05$) as assessed by Shapiro-Wilk's test of normality. There was no statistically significant three-way interaction between application of the White Plus Solution, brand of zirconia, and thickness of zirconia $F(1, 72) = 0.122$, $p = .728$. Statistical significance was accepted at the $p < .05$ level for simple two-way interactions and simple simple main effects. There was a statistically significant simple two-way interaction between the brand of zirconia and application of the solution, $F(1, 72) = 5.276$, $p = .025$, and application of the solution and thickness of the wafer $F(1, 72) = 10.708$, $p = 0.002$ but not for the brand of zirconia and the thickness of the wafer, $F(1, 72) = 0.950$, $p = .333$. All simple simple pairwise comparisons were run for the brand of zirconia and application of solution as well as application of solution and thickness of the wafer, with a Bonferroni adjustment applied. ΔE values in the treated Ivoclar group were 0.892 ± 0.15; in the untreated Ivoclar group 1.615 ± 0.14, in the treated Katana group 0.807 ± 0.128, and in the untreated Katana group 1.42 ± 0.078. There was a statistically significant mean difference in the ΔE values between the brand of zirconia and treatment with solution pairwise comparison. This is looking at the effect the IDS CAD White Plus solution had on the different brand's ΔE values. The mean difference between the treated Ivoclar group and the untreated Ivoclar group was 0.723 (95%CI, 0.656 to 0.791), $p < .05$. The mean difference between the treated Katana group and the untreated Katana group was 0.613 (95%CI, 0.546 to 0.681), $p < .05$. There was also a statistically significant mean difference in the ΔE values between the treatment with solution and the brand of zirconia pairwise comparison. This is looking at the effect the brand had on the function of the IDS CAD solution (or the differing effect of the solution on a specific brand). The mean difference between the treated Ivoclar group and the treated Katana group was 0.085 (95%CI, 0.18 to 0.152), $p < .05$. The mean difference between the untreated Ivoclar group and the untreated Katana group was 0.195 (95%CI, 0.127 to 0.262), $p < .05$. There was also a statistically significant mean difference in the ΔE values between the treatment with the solution and the thickness of the wafer pairwise comparison. The mean difference between the 1.0mm treated group and the 1.00mm untreated group, was 0.747 (95%CI, 0.679 to 0.814), $p < .05$. The mean difference between the 0.7mm treated group and the 0.7mm untreated group was 0.590 (95%CI, 0.523 to 0.657), $p < .05$. This is looking at the effect the chang had on that specific thickness. There was also a statistically significant mean difference in the ΔE values between the thickness of the wafer and the treatment with solution pairwise comparison. This is looking at the effect that the thickness of the wafer had on the IDS CAD solution itself. The mean difference between the 1.00mm treated group and the 0.7mm treated group was 0.195 (95%CI, 0.128 to 0.262), $p < .05$. There was not a statistically significant mean difference between the 1.00mm untreated group and the 0.7mm untreated group.

Another three-way ANOVA was conducted to determine the effects of IDS CAD White Plus Solution, brand of zirconia, and thickness of zirconia on the ΔE value over the titanium stumpf. Data are mean ± standard deviation, unless otherwise stated. There were no outliers in the data assessed as a value greater than 3 box-lengths from the edge of the box. ΔE values were normally distributed ($p > .05$) as assessed by Shapiro-Wilk's test of normality. There was no statistically significant three-way interaction between application of the White Plus Solution, brand of zirconia, and thickness of zirconia $F(1, 72) = 0.092$, $p = .618$. Statistical significance was accepted at the $p < .05$ level for simple two-way interactions and simple simple main effects. There were also no statistically significant simple two-way interactions between the brand of zirconia and application of the solution, $F(1, 72) = 3.316$, $p = .325$, application of the solution and thickness of the wafer F(1, 72) = 7.678, p = 0.222, or for the brand of zirconia and the thickness of the wafer, $F(1, 72) = 1.940$, $p = 0.433$.

CHAPTER 5: DISCUSSION

Clinical significance of the ΔE values that were found was determined by comparing those color difference values to the perceptibility and acceptability thresholds as determined by Douglas et al[5,] and Johnston and Kao[4], where ΔE > 2.6 was considered clinically perceptible, and a ΔE < 3.7 was considered clinically acceptable. The ΔE values generated by this study, while found to be statistically significant, did not ever reach these aforementioned thresholds for perceptibility or acceptability. With our ΔE values ranging from 0.34 (for treated 1.0 mm thick Katana wafers) at the very low end to 1.63 at the very high end (for untreated 0.7 mm thick Ivoclar wafer), none even approached a threshold for being clinically perceptible (ΔE > 2.6). (Table 2) Therefore, even though we can say the solution does reliably reduce the ΔE value when it is applied to the zirconia, it does not have a great enough effect to be perceptible to the average person. Therefore, it cannot be said that application of the solution produces a clinically significant result.

Regardless of its clinical significance, or the lack thereof, the IDS CAD solution did consistently and reliably produce opacity on the sintered zirconia in a statistically significant manner. The mean ΔE value of the untreated zirconia wafers was 1.51 over the ND8 stumpf, and decreased to a mean ΔE value of 0.85 when the wafers were treated with the solution (Table 3). The mean ΔE value of the untreated zirconia wafers was 0.74 over the Titanium stumpf, and decreased to a mean ΔE value of 0.41 when the wafers were treated with the solution (Table 4). The treated ΔE values were also consistently greater for the 0.7mm thick wafers than for the 1.0mm thick wafers. The mean ΔE for 0.7mm wafers over the ND8 stumpf was 0.95 versus 0.75

for the 1.00 mm wafers (Table 3). The mean ΔE for 0.7mm wafers over the titanium stumpf was 0.45 versus 0.36 for the 1.00 mm wafers. This stands to reason that the more translucent, thinner 0.7mm thick wafers would benefit more from the increased opacity produced by the solution than the thicker, less translucent 1.0mm thick wafers.

It is worth mentioning that for the values measured over the ND8 stumpf, there were two outliers in the 1.0 mm thick untreated ZirCAD MO wafer group. It was determined those values should be incorporated into the data because when compared to the ranges seen in the other groups, they were well within those value ranges. These values were outliers in their group simply because the rest of the values in that group had a much narrower range than in the other sample groups.

The three-way ANOVA was conducted to help discern how the different variables came together and interacted together with each other to effect the ΔE value. The three-way ANOVA showed that our three variables (the application of IDS CAD White Plus Solution, the brand of zirconia, and the thickness of zirconia) did not come together in a statistically significant three-way interaction to cause an effect on the ΔE value. However, for the ND8 stumpf, statistically significant simple two-way interactions between brand of zirconia and treatment, as well as treatment and thickness of wafer were noted, but not for brand of zirconia and thickness of wafer. Simple simple pairwise comparisons were run for those two significant two-way interactions to attempt to determine which of the variables was having the statistically significant effect. For the brand and treatment pairwise, the effect the solution had on the brand's ΔE values was found to be statistically significant. That is to say, there was a notable change in the ΔE values on wafers that were treated with the solution, versus those that were not treated with the solution. Conversely, looking at the effect the brand of zirconia had on the function of the solution was also found to be statistically significant. That is, the effect of the chang solution was slightly different between the two brands. It affected the ΔE value in both brands, but not to the same degree – there was a statistically significant difference in the effect. Since the chemical mechanism of the solution is proprietary and unknown, we may infer that there is some difference in the chemical makeup between the two different brands of zirconia that causes a slight difference in their chemical reaction with the solution. This could be due to slightly different composition of the zirconia or perhaps differences in the fabrication method of the zirconia pucks that make them more susceptible to the effects of the solution.

There was also a statistically significant mean difference in the ΔE values between the treatment with the solution and the thickness of the wafer pairwise comparison. This is looking at the effect the treatment had on that specific thickness of zirconia. We can see that the thinner wafers benefited from a greater difference in ΔE values when they were treated with the solution. That could simply be a function of their translucency to begin with, or it could suggest that the solution works differently on different thicknesses of zirconia. Conversely, there was also a statistically significant mean difference in the ΔE values between the thickness of the wafers and the treatment with the solution. This is looking at the effect that the thickness of the wafers had on the solution itself. This statistically significant interaction could suggest that something about the thickness of the wafer actually makes the solution more or less effective when it is applied and sintered.

Another point that bears mentioning is a key limitation to our study in the absence of a cement layer between the zirconia sample and substrate. Clinically, there would always be a layer of cement between the treated, opacified zirconia and the substrate. This could affect the

ΔE values in a myriad of ways and the fact that it was missing from our tabletop study could be one key explanation as to why our results yielded ΔE values that were not clinically significant.

CHAPTER 6: CONCLUSION

Within the limitations of this benchtop study, the application of the IDS CAD White Plus solution did function as intended to opaque the zirconia and reduce the ΔE value of the zirconia over both the ND8 and the Titanium stumpf. However, none of the ΔE values calculated were above the minimum ΔE required to be perceptible to the human eye (2.6 from our literature review), or the minimum ΔE found to be clinically unacceptable (3.7 from our literature review). Because all of the ΔE values calculated were below the average perceptibility and acceptability thresholds, there is no clinical significance.

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TABLES

Table 1. Materials investigated: types of zirconia, manufacturer, and size of wafers.

Material	Manufacturer	Wafer Size
IPS e.max ZirCAD (MO) Shade A2	Ivoclar Vivadent, Schaan, Liechtenstein	10 mm x 10 mm x 0.7 mm 10 mm x 10 mm x 1.0 mm
KATANA Zirconia (HT) Shade A2	KurarayNoritake, Tokyo, Japan	10 mm x 10 mm x 0.7 mm 10 mm x 10 mm x 1.0 mm

Table 2. Summary of mean ΔE Values for Ivoclar ZirCAD (MO), indicated with an "I," and for Katana HT, indicated with a "K." Untreated wafers are marked as "Plain" and wafers treated with IDS CAD White Plus Solution ("Chang Solution") are marked as "Chang."

1 I Plain		1 I Chang		0.7 I Plain		0.7 I Chang	
ND8	Titn	ND8	Titn	ND8	Titn	ND8	Titn
1.603333333	0.69	0.81	0.39333333	1.62666667	0.84666667	0.97333333	0.473333334
0.144401703	0.17850545	0.16781089	0.11088867	0.14384491	0.17227598	0.06813204	0.066295261

ND8	Titn	ND8	Titn	ND8	Titn	ND8	Titn
1.393333333	0.65	0.69333333	0.34333333	1.44666667	0.78666667	0.92	0.42
0.096609179	0.07243558	0.05163978	0.03162278	0.04499657	0.05018484	0.05708992	0.047661357
1 K Plain		1 K Chang		0.7 K Plain		0.7 K Chang	

Table 3. Mean ΔE Values for the zirconia wafers (both brands) over the ND8 stumpf.

Mean DELTA E over ND8		
Untreated		1.51
Untreated 1.0mm		1.49
Untreated 0.7mm		1.53
Treated		0.85
Treated 1.0mm		0.75
Treated 0.7mm		0.95

Table 4 - Mean ΔE Values for the zirconia wafers (both brands) over the Titanium stumpf.

Mean DELTA E over Titanium		
Untreated		0.74
Untreated 1.0mm		0.67
Untreated 0.7mm		0.81
Treated		0.41
Treated 1.0mm		0.36
Treated 0.7mm		0.45

FIGURES

Figure 1. Munsell Color System illustrating the three-way interaction between value, hue, and chroma.

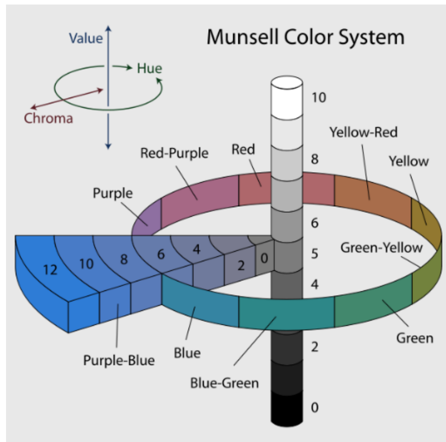

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Figure 2. ΔE Values for the Ivoclar ZirCAD MO wafers and Katana HT wafers over the ND8 Stumpf. Wafers treated with IDS CAD (Chang) Solution are marked as "with Chang" and untreated wafers are marked as "without Chang."

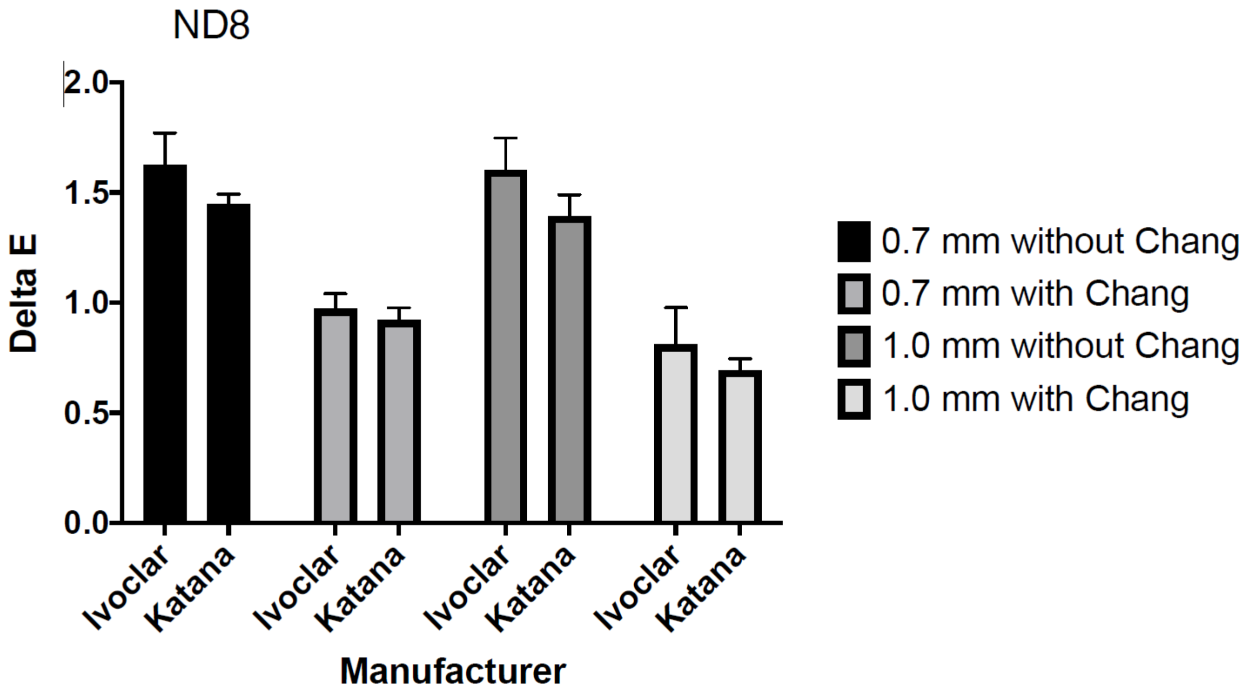

Figure 3. ΔE Values for the Ivoclar ZirCAD MO wafers and Katana HT wafers over the Titanium Stumpf. Wafers treated with IDS CAD (Chang) Solution are marked as “with Chang” and untreated wafers are marked as “without Chang.”

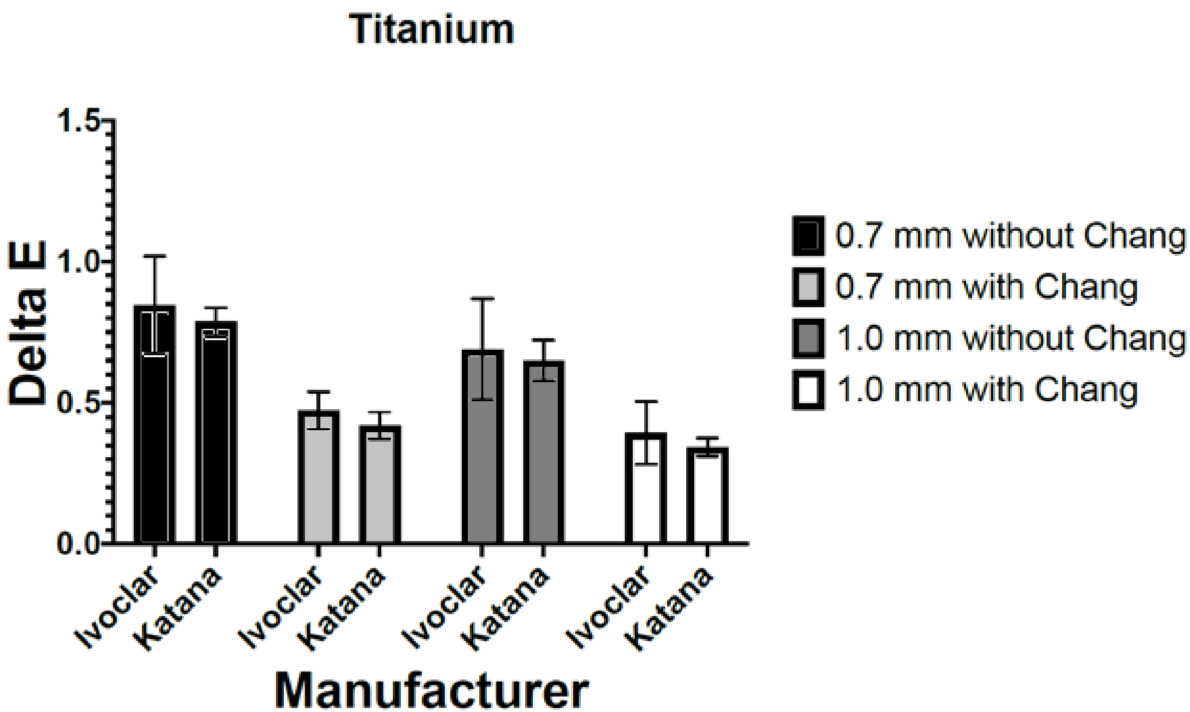

Figure 4. ΔE Values for Ivoclar ZirCAD MO zirconia wafers. Wafers treated with IDS CAD (Chang) Solution are marked as "Treated" and untreated wafers are marked as "Plain."

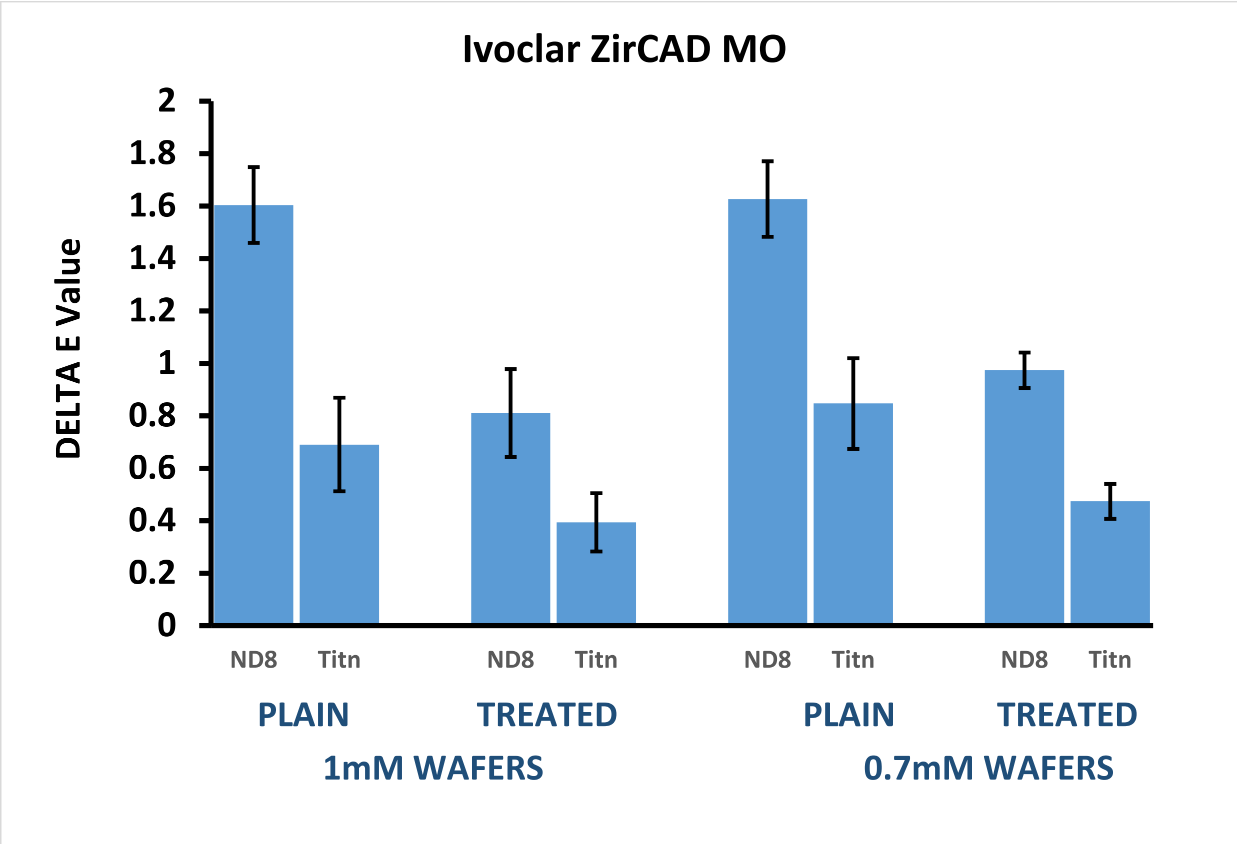

Figure 5. ΔE Values for Katana HT zirconia wafers. Wafers treated with IDS CAD (Chang) Solution are marked as "Treated" and untreated wafers are marked as "Plain."