



School of
Dental Medicine

**Influence of Crown and Abutment Material on the Color of All-ceramic
Screw-retained Implant Fixed Prosthesis.**

A Thesis

Presented to the Faculty of Tufts University School of Dental Medicine
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Dental Research

by
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August 2021

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ABSTRACT

Statement of the problem: There are various ceramic material systems available for implant-supported restorations. However, the influence of implant abutment materials and crown materials on the final color of these systems is still uncertain.

Purpose of the study: The purpose of this in-vitro study was to evaluate the effect of different (i) abutment materials (titanium base abutment and titanium abutment with zirconia coping) and (ii) crown materials (lithium disilicate and zirconia) on the final color of all-ceramic screw-retained implant crowns, measured at the cervical location by spectrophotometric analysis.

Materials & Methods: A sample size of $n=16$ per group was obtained based on a pilot study and subsequent power calculation. A maxillary typodont was modified to resemble a partially edentulous arch with a missing central incisor that was replaced with an implant. The typodont was then scanned and identical monolithic screw retained implant crowns were designed in order to fit two different abutments: titanium base abutment and titanium with zirconia coping abutment. The crowns were milled in shade A1 using two different ceramic material: The Medium Translucent Lithium disilicate and the High Translucent Multilayered Zirconia. A spectrophotometer was used to measure the color difference (ΔE). The database of VITA shade A1 in the spectrophotometer software will serve as a control group. Welch's ANOVA was used to evaluate color differences between the tested groups.

Results: The highest ΔE mean was recorded for group 1: Lithium disilicate crown on the titanium base abutment (3.44 ± 0.27), followed by group 2: Lithium disilicate crown on the titanium base abutment with zirconia coping (2.60 ± 0.24), whereas the lowest ΔE mean was

recorded for group 3: HTML zirconia on the Titanium base abutment (2.07 ± 0.10). The means of all groups were significantly different ($p < 0.001$).

Conclusion: Mean ΔE of Lithium disilicate on titanium base abutment (group 1) was higher compared to Lithium disilicate on titanium and zirconia abutment (group 2), and Zirconia on titanium base abutment (group 3) had the smallest mean ΔE .

DEDICATION

To my best friend, Maryam Alsaffar, who has been a pillar of support and encouragement.

To my husband, Michael Zhang, for your love, support, and friendship.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude my principal advisor, Dr. Kiho Kang who inspired me and guided me throughout the process and postgraduate program.

I would also like to thank the rest of my thesis committee and faculty (Mr. Yukio Kudara, Dr. Yong Jeong Kim, Dr. Gabriela Lagreca, Dr. Khaled El Rafie, Dr. Sarah Pagni, Dr. Ali Muftu). They have been supportive throughout my postgraduate program and have offered their encouragement, insight, and guidance for my thesis.

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**Influence of Crown and Abutment Material on the Color of All-ceramic
Screw-retained Implant Fixed Prosthesis.**

INTRODUCTION

Implant restoration has been a popular option to restore edentulous area, and the esthetic outcome is a critical determinant for the success and patients' satisfaction regarding implant prosthesis in the maxillary anterior region.¹⁻³

Implant supported prostheses can be accomplished by attaching fixed prosthesis to implants with a screw or by cementing the prostheses on implant abutments attached to implants with screws.⁴ The screw retained implant restoration has been a popular option because of its physical and biological properties.

Porcelain fused to metal has been commonly used in dentistry as an esthetic restorative material for fixed partial dentures such as crowns and bridges. However, metal-free all ceramic material has become more popular in recent years with improvement in physical properties and amazingly natural esthetics and color rendering.⁵ Dental prostheses made from all ceramic materials can provide similar appearances of natural teeth and the use of all ceramic has increased significantly.^{6,7} With recent advancements for dental implant restorations, all ceramic screw retained prostheses can be fabricated by cementing zirconia or lithium disilicate crowns to titanium base abutment. However, the background effect of titanium base abutment can be challenging for the esthetic outcome in cases of using translucent ceramic materials.

Several clinical attempts have been made to overcome the dark background effect of titanium base abutment to achieve optimal esthetic outcome. Data of the effect of background effect titanium abutments on the white esthetics outcome of full contour ceramic crown are limited, and the influence of implant abutment materials and crown materials on the final color of these systems is still uncertain. The purpose of this study is to compare the effect of

different ceramic crown material and abutment material on the color outcome of implant screw-retained prostheses.

BACKGROUND

Cement versus screw-retained Implant Fixed Prosthesis

Cement retained implant prostheses are a common choice in implant dentistry. The advantages of the cement-retained option are that it allows compensation of implants that are not prosthetically ideally placed, avoid the screw access channel be placed in an esthetic area, or avoid the interference on the screw access hole during protrusive and lateral excursive movement; therefore, the cement-retained design is often considered more esthetic and easier to control occlusion.⁸ For patients with limited jaw opening, considering the final crowns and instruments' access, it is easier to restore the implants with cement-retained design.⁹

However, the most concerning drawbacks for cement-retained prostheses is excess cement left behind the soft tissue surrounding the cement-retained implant¹⁰, especially challenging for prefabricated abutments, where the margin can be millimeters subgingival¹¹, which causes inflammation and makes the tissue less healthy, and has been associated with the development of peri-implant diseases such as peri-implant mucositis and peri-implantitis.

The main advantage of screw-retained implant prosthesis is retrievability. If the prosthesis needs to be removed because of technical or biological complications, the screw-retained design allows easy removal without causing more damage. Higher biological compatibility was found with a screw-retained prosthesis than with cement-retained.¹²⁻¹⁴ Because the minimum abutment height to use cement-retained prosthesis with predictable retention was documented to be 5 mm, screw-retained prosthesis is the choice when the restorative space is limited.⁹

However, drawbacks of a screw-retained design are that this prosthesis can be challenging to sit on the implant platform and makes the prostheses' clinical adjustment more

challenging.⁴ Screw-retained implant prostheses require precise placement of the implants to achieve a predictable esthetic outcome and optimal occlusion because of the screw access channel.

Types of Cement-retained Implant Fixed Prosthesis

Cement retained prostheses can be placed on either prefabricated stock or customized made abutments. Prefabricated abutments are a common choice because of reduced laboratory working time and cost but can only be adjusted partially to meet clinical requirements. Custom abutments can shape the soft tissue margin more ideally and provide optimal emergence profile.¹⁵

Titanium and gold abutments are a common choice for cement-retained implant prostheses because of superior physical and biological properties.¹⁶ Titanium abutments have been the most commonly used because of the material properties and high estimated 5-year survival rate of 97.4%.¹⁷ However, the prosthesis's final color may be affected by the underlying metal abutment when titanium abutments are restored with ceramic crowns.¹⁸ To meet esthetic demand, the zirconia abutment was developed, and the physical and optical properties made it widely used in the esthetic zone.¹⁹ But several reports indicated the complications of zirconia abutment, including fracture and wear of implant internal connection.²⁰⁻²²

Types of Screw-retained Implant Fixed Prosthesis

The material of choice for screw-retained implant prosthesis can be porcelain fused to metal (P.F.M.) metal-ceramic or all-ceramic restoration. A PFM screw-retained prosthesis

requires the use of U.C.L.A. abutment. Following waxing the U.C.L.A. abutment to the ideal substructure design, it will be cast. After casting, the metal abutment will be layered with an opaque material and then layered with feldspathic porcelain. Metal-ceramic implant-supported single crowns have a high estimated 5-year survival rate of 98.3 % in the literature and are the gold standard option.²³

However, P.F.M. is not the most esthetic material of choice for reconstruction; there have been reports of veneering ceramic chipping and increasing noble alloy costs. This led to the development of using other monolithic ceramic such as lithium disilicate or zirconia.^{24, 25} An all-ceramic screw-retained prosthesis requires a titanium base. Prefabricated titanium base abutment was developed to allow for a titanium-to-titanium connection with the implant, also achieve superior esthetics with ceramic abutments.²⁶

The crown is made from zirconia or lithium disilicate, and then it is cemented to the titanium base. All-ceramic implant crowns are working well clinically and have recently been the subject of considerable research and showed similar survival rates to P.F.M. implant prosthesis (5-year survival rate of 97.6% for zirconia and 5-year survival rate of 98.7 % for lithium disilicate²⁷), making implant-supported all-ceramic a possible treatment option.

Titanium base abutments can be used to fabricate hybrid abutment, which requires fabrication of a zirconia coping and cemented to the Titanium base. Recently, another type of screw-retained fixed prosthesis has been introduced for improved esthetics. By cementing ceramic protheses to the zirconia coping or the zirconia framework on the titanium base to overcome the drawbacks of porcelain chipping fused to zirconia prosthesis²⁸ and to hide the metal effect of the titanium base²⁹. The custom zirconia coping cemented to the Titanium base and the crown cemented to the zirconia coping both require screw access holes to

fabricate screw cementable prostheses.

Optical property of Lithium Disilicate

Lithium disilicate is a glass-based ceramic material and provides good esthetic restoration due to the optical properties.³⁰ The translucency of lithium disilicate can provide natural tooth-like restoration but can be challenging in hiding the titanium base abutment.

Based on levels of pre-crystallization treatment, there are different variety of translucent lithium disilicate CAD/CAM blocks. high translucency (HT) material contains a small number and bigger size of lithium metasilicate crystals in the pre-crystallized state, while low translucency (LT) material contains a larger number of smaller of lithium metasilicate crystals. Following complete crystallization heat treatment at 850 °C for 10 minutes, the fully crystallized high translucency (HT) lithium disilicate material has covered lithium disilicate crystals ($1.5 \times 0.8 \mu\text{m}$) in a glassy matrix, whereas the fully crystallized low translucent (LT) lithium disilicate has a large number of small, interconnected lithium disilicate crystals ($0.8 \times 0.2 \mu\text{m}$) along with spherical pores.³¹

Lithium disilicate ceramic can be used as ceramic frameworks with veneer porcelain layered to achieve optimal beauty and with its light scattering and fluorescent properties to resemble those of the natural teeth.^{32, 33} However, the veneering porcelain chipping is one of the common clinical complications of all-ceramic restorations.^{34, 35} With its variety of translucency levels and shades, lithium disilicate can be fabricated as a monolithic restoration with surface characterization and has been widely used for esthetic monolithic ceramic crowns.³⁶⁻³⁸

Optical properties of Zirconia

Zirconia is a heterogeneous, high resistant, polycrystalline ceramic characterized by excellent mechanical properties. Zirconia is usually considered an opaque restorative material with optical and esthetic properties less attractive than glassy ceramics, particularly in terms of translucency.³⁹ In the past, one of the drawbacks of zirconia was that the color was very opaque. Recently, to enhance the esthetic properties of the material, translucent zirconia has been introduced in the market. The first monolithic translucent yttria-stabilized tetragonal zirconia polycrystal was introduced first by Katana (Kuraray Noritake, Japan) in 2013 and this material has had revolutionary impact to the world of zirconia. Three different levels of translucency are available: Ultra Translucent Multilayered zirconia (UTML), Super Translucent Multilayered zirconia (STML) and High Translucent Multilayered zirconia (HTML). Ultra-Translucent Multilayered zirconia and Super Translucent Multilayered zirconia have very high light transmission, but the strength of the zirconia material drops with translucency increased⁴⁰

The translucent zirconia is also multilayered, aiming to resemble a natural tooth color gradation from darkest cervically to the lightest towards the incisal edge ensuring a natural esthetic monolithic restoration. It may provide less complicated procedures compared with the production of multilayered restorations with opaque zirconia cores and feldspathic veneers and can reduce the complication of veneer chipping of multilayered ceramic restorations.⁴¹

Effect of abutment color on the of All Ceramic Restorations

Shade masking to reduce the black background effect from titanium base abutment is

one of the esthetic challenges in the all-ceramic screw-retained prosthesis in the anterior esthetic zone, especially when using lithium disilicate and zirconia with translucency to provide natural tooth color restoration to achieve a favorable esthetic outcome.

Several studies discussed the thickness of ceramic required to mask a dark substrate. It is suggested to have a minimal 1.6mm thickness of a ceramic restoration on a gold abutment⁴², 2.5mm thickness for high translucent lithium disilicate to mask dark substrates⁴³, 0.8 mm semi-translucent zirconia has been requested when used over discolored substrates to ensure adequate masking ability⁴⁴, and bilayer ceramic crowns with 0.8mm zirconia coping with either high translucent or low translucent 1mm lithium disilicate can adequately mask copper and silver metals.⁴⁵

Color in Dentistry

The appearance of natural tooth color is a complex phenomenon and is composed of several semitranslucent layers of enamel and dentin that absorb, reflect, transmit, or refract part or all incident light.⁴⁶

Shade determination and shade duplication are the two key phases for color replication of dental ceramics in order to achieve natural tooth appearance. Reliable delivery of a properly matched restoration to existing porcelain restorations can be ensured when using the shade assessment method.^{47, 48} Shade selection and determination can be performed either by visual shade matching or instrumental analysis. Shade determination of natural teeth can be difficult because of light source, surface texture, translucency, and the color of the background environment may have alteration in an observer's perception of color.

The shade duplication is done by using corresponding shade of ceramic materials. Color discrepancy between final prostheses and the original matched shade could be masked by applying surface characterization porcelains. However, the process of color assessment and replication is still critical in terms of achieving an esthetic restoration. Accurate visual assessment by clinicians and reproducible transfer to the laboratories of tooth color information are the requirements of successful color matching.⁴⁶

Two systems are commonly used in dentistry of color description. Munsell Color Order System is more visually descriptive, whereas CIELAB color system is more quantitative.

Munsell Color System

The Munsell color system is based on the steps of visual perception, with any color being defined as a point within the three-dimensional Munsell color space.

Hue, Chroma, and Value are the three components of a color space which specifies colors in this system.⁴⁹ Hue is referred as “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.”⁴⁹ Hue represents the basic color tone and among different groups of color and is defined as the particular variety of a color. The hue of an object can be red, green, yellow, and so on. Chroma describes the level of color saturation, and it is defined as the strength of color, intensity of hue or vividness.⁴⁹ An object with the lower chroma will show the less purity of the color. Value is defined as the relative lightness or darkness of a color or the brightness of an object.⁴⁹ Value specifies the brightness of color depending on the amount of greyness in color, ranging from pure black to pure white.

The Munsell color system was the first to describe the colors in three-dimensional space

systematically. It has been widely used in dentistry to quantify color as a standard system of color specification.

CIELAB Color System

The CIELAB color order system was developed by the Commission Internationale de l'Eclairage (CIE, International Commission on Illumination). It is also a three-dimensional color space, but the shade is defined expressed based on the L^* , a^* and b^* three coordinates with standardization of light sources and of observers. The coordinates a^* and b^* describe the chromatic characteristics of the color. a^* represents the green to red while b^* represents from blue to yellow. L^* describes the achromatic character of the color, resembles the lightness from black to white.⁵⁰ The CIELAB is designed to approximate human vision. The L^* component closely matches human perception of lightness, improving the interpretation of color measurements.

The differences in color can be described in units allowing clinical interpretation of visual perception, and this makes it possible to define color difference between different material such as ceramic and tooth with quantification. The difference between two colors can be calculated with the equation: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$

Visual shade matching

Shade selection and color determination is a critical and challenging part of esthetic dentistry. Shade selection and color determination can be done either through visual technique or through instrumental technique.

Visual technique utilizing shade guides to assess shade and translucency is most

commonly applied method in dental clinical practice. The Munsell color system is utilized; the three dimensions of color are described in terms of Hue, Value and Chroma.

Visual technique can be affected by several factors, such as light source, observer's perception, background environment.⁵¹ Therefore, visual technique is difficult to apply with accuracy and the result can be unreliable, and the technique is often considered subjective and inconsistent.^{52 53-55} It is fortunate that a natural look prosthesis doesn't need to be an exact duplication of the adjacent teeth, but it should still have the ability to blend in with the surrounding teeth.

Instrumental color determination

Instrumental technique such as intraoral scanner, spectrophotometers, and colorimeters have been used in dentistry to help in color determination, and are expected to enhance the accuracy of shade matching as well as the interpretation and fabrication of dental restorations.^{56 57}

The instrumental technique can remove the issues of human color perception and provide a more predictable color reading outcome, and several studies supported that the color determined by instrumental technique were more reliable than the visual shade matching technique.^{58 59-62} However, one other study showed inconsistent shade reading among different clinicians utilizing color instrument.⁶³ It should be noted that the color determination outcome can be deviated when the clinicians have different levels of training and or the different positioning of the probe tip.

Colorimeter

Colorimeters have been used in the color industry for decades. Colorimeter is an optical reading device that can assess the dominant wavelengths of objects are reflected back to its sensors in the red, green, and blue areas of the visible spectrum.⁶⁴

The way the colorimeter measures color is designed in a way that is similar to how the human eye evaluates color. When tested compared to human eye observation, the results were inconclusive.⁶⁴⁻⁶⁷ The instruments are fabricated to measure flat surfaces, and the results are very accurate when assessing opaque color objects.⁶⁸ But the color reading is significantly affected with surface texture, outline contour and wet dry condition, and the accuracy and repeatability can be impacted and outcome can be more prone to errors when above conditions are involved. The use of colorimeter as an additional help in color matching and determination system can still improve the accuracy of shade analysis, communication, interpretation, and fabrication of dental restorations.⁶⁹

Intraoral scanner

With the advancement of digital scanning technology, some intraoral scanners are able to capture clear color images of soft and hard tissue structures while scanning impression images.^{64, 70-72} It is possible to use the color images captured from intraoral scanners for color determination with visual shade guides.⁷³ However, since the color accuracy of the digital scanner compared to other instrumental technique is still uncertain⁷³, using solely the intraoral scanner as color determination device is still not guaranteed, it is recommend to use with combination of other technique or device.

Spectrophotometer

The spectrophotometer can quantify color through CIE-Lab (1971) parameters (Commission Internationale de l'Eclairage, L = lightness, a = chroma along the red-green axis, b = chroma along the yellow-blue axis) by detecting the quantity of light energy reflected from an object⁷⁴, and the data obtained allows mathematical comparison by calculating the difference in two colors as ΔE .

Multiple studies supported using spectrophotometer in the dental application of shade selection because of its objective and quantitative color information.^{58, 63, 75-78} The accuracy of shade assessment, reproducibility of the color information, and standardization of measuring process make spectrophotometer superior to human eyes for shade taking.^{57, 60, 69}

Spectrophotometers are considered one of the most accurate color measuring devices in dentistry.^{60, 61} A systemic review done by Chen *et al.* found that devices among instrumental techniques including colorimeter, digital imaging, shade matching, and spectrophotometer, that spectrophotometers are the most accurate devices for color determining of tooth.⁷⁹

In recent years, different spectrophotometers have been introduced to the dentistry market. Crystaleye (Olympus, Tokyo, Japan) is a spectrophotometer which has digital photography features. Da Silva *et al.* assessed the performance of the Crystaleye and concluded that this spectrophotometer is simpler and more accurate in comparison to the traditional spectrophotometer.⁴⁶ However, the precision of the spectrophotometer was not reported. Odaira *et al.* assessed the Crystaleye spectrophotometer and concluded that the Crystaleye spectrophotometer is an easy to use device and generates accurate color measurements under dental clinical conditions and the system improves the color replication process objectively.⁸⁰

AIM AND HYPOTHESES

Aim

To evaluate the effect of different (i) abutment materials (titanium base abutment and titanium abutment with zirconia coping) and (ii) crown materials (lithium disilicate and zirconia) on the final color of all-ceramic screw-retained implant crowns, measured at the cervical location by spectrophotometric analysis.

Hypotheses

The hypotheses proposed were (i) The lithium disilicate crown on titanium base abutment (group 1) will have greater ΔE when compared to the lithium disilicate crown on titanium abutment with zirconia coping (group 2). (ii) The lithium disilicate crown on titanium base abutment (group 1) will have greater ΔE when compared to the high translucent multilayered zirconia crown on titanium base abutment (group 3). (iii) The lithium disilicate crown on titanium base abutment with zirconia coping (group 2) will have greater ΔE than the high translucent multilayered zirconia on titanium base abutment (group 3).

Clinical Implication

The knowledge learned from this study may assist the practitioner in predicting the final color of screw-retained all ceramic prostheses fabricated from lithium disilicate glass ceramic or zirconia ceramic in cases of different color abutment by determining the level of translucency and background color will affects the overall color of CAD/CAM all ceramic implant prostheses.

MATERIALS AND METHODS

Typodont preparation

A maxillary typodont (Nissin, Japan) was modified by removing the right central incisor (#8) to simulate a partially edentulous arch. A bone level implant replica (4.1 mm Regular Crossfit, Straumann, Switzerland) was inserted 3 mm at the subgingival level in the central incisor position (Figure 2). A scan body (CARES Mono Scan Body, Straumann) was attached to the implant replica (Figure 3), and the typodont was sprayed with an indicating spray (Quickcheck Indicating Spray, white, Vacalon Company Inc, Pickerington, OH) and the typodont was scanned with a laboratory scanner (CARES, 7SERIES, Dental Wings, Straumann) and an intraoral scanner (Omnicaam, Cerec, Densply).

After scanning the typodont, horizontal lines at 3mm coronally from the gingival level were made in the adjacent teeth (#7 and #9) and one vertical mark was made on the artificial gingiva in the middle of the crown of #8 to standardize the location of the subsequent color measurements (Figure 4).

Specimen design and fabrication

The 3D digital data were inserted into computer design software (DentalCAD, V2.3, Matera, Exocad; Omnicam, Cerec, Densply) to design a zirconia coping and identical contour of monolithic screw-retained lithium disilicate and zirconia crowns to fit the fit 5.5 mm ti-base abutments (Variobase for the crown, R.C., Gingival Height 2 mm, Straumann). A 0.8 mm thickness zirconia coping in shade was milled using a laboratory milling machine (Cut, Schutz Dental) utilizing discs from Katana (Kuraray Noritake, Japan) zirconia in High

Translucent (H.T.) shade 12 (Figure 7). Lithium disilicate crowns in shade A1 were milled using a laboratory milling machine (Cerec, MCX) utilizing blocks from Ivoclar Vivadent I.P.S. e.max CAD Low translucency (L.T.). Zirconia crowns in shade A1 were milled using a laboratory milling machine (Cut, Schutz Dental) utilizing discs from Katana (Kuraray Noritake, Japan) zirconia in High Translucent Multilayered zirconia (H.T.M.L.). The zirconia crowns, lithium disilicate crowns and the zirconia coping were then sintered using sintering furnace (Mihm-Vogt Dental Geratebau GmbH & Co. KG; (Programat, P3, Ivoclar Vivadent) following the manufacturer's instruction.

In order to resemble clinical conditions, each crown was then finished, hand polished and glazed with a Cotton Buff Wheel (Brasseler, USA) and Pearl Surface Z porcelain polishing paste (Kuraray Noritake Dental Inc., Japan) for 30 seconds for each surface using the same speed by the same operator (MA) to ensure standardization.

Samples were divided into 3 main subgroups depending on the prostheses design. These subgroups were divided as follows:

1. LT lithium disilicate crowns with Variobase
2. LT lithium disilicate crowns with Variobase and zirconia coping
3. HTML zirconia crowns with Variobase

The database of VITA shade A1 in the spectrophotometer software will serve as a control group.

Color measurement

Milled crowns were placed on the corresponding abutments with the clear try-in paste

(P.A.N.A.V.I.A., V5 Try-In-Paste, Kuraray, Noritake) (Figure. 5) The typodont was inserted in a black box that served to eliminate the impact of the external light (Figure. 7). The Crystaleye (Olympus, Tokyo, Japan) spectrophotometer was calibrated before each measurement. Each sample's image was captured according to the manufacturer's instructions. To ensure the standardization of the size and location of the specimen, the coordinates on the screen of the spectrophotometer were utilized before capturing the image (Figure. 8).

After taking each measurement with the Crystaleye spectrophotometer, the position of measurement rectangles was moved manually with the computer cursor by the same operator (JC). All the locations were evaluated and approved by another operator (KK) to maintain consistency of location (Figure 9).

Color difference of each group was compared to the control (VITA shade A1 in the spectrophotometer software) utilizing the ΔE formula which is calculated through the software automatically (Figure 10).

STATISTICAL ANALYSIS

Sample Size Calculation

A sample size calculation was performed in nQuery Advanced with data from the pilot study assuming a type I error of 1.7% and a mean (SD) of 3.372 (0.122) for group 1, 2.624 (0.214) for group 2, and 2.044 (0.109) for group 3. To have a type II error of 20% when comparing group 2 and group 3, 16 samples per group were required, giving 48 samples total. This is less than 1% type II error for the other comparisons.

Statistical Analysis

Descriptive statistics (means and standard deviations for continuous items, counts, and percentages for categorical items) were calculated.

Normality was assessed graphically and with the Kolmogorov-Smirnov test. Differences in variance were examined with Levene's test. The variances of the groups were not equal, Welch's ANOVA was used to compare sample means and the Games Howell test will be used for post-hoc pairwise comparisons. All p-values less than 0.05 were considered statistically significant. S.P.S.S. version 27 was used for the statistical analysis.

RESULTS

A total of 48 specimens were fabricated and tested. A summary of the descriptive statistical analysis of the results showing the mean color difference (ΔE) and the standard deviation for all the groups is shown in (Table 1). For illustration, bar graph of the values for ΔE of the tested groups are shown in (Fig.11). The Welch's ANOVA statistical test revealed significant differences between the 3 experimental groups ($p < 0.001$). The Lithium disilicate crown on the titanium base abutment (group1) had the highest mean ΔE and standard deviation (3.44 ± 0.27), followed by Lithium disilicate crown on the titanium base abutment with zirconia coping (group 2) (2.60 ± 0.24). The HTML zirconia on the Titanium base abutment (group 3) reported the smallest mean ΔE and standard deviation (2.07 ± 0.10). Pairwise, all 3 groups are different from one another ($p < 0.001$).

DISCUSSION

This in-vitro study evaluated the effect of different abutment and crown materials on the final color of all-ceramic screw-retained implant crowns at the cervical location.

The first hypothesis of this study was that the lithium disilicate crown on titanium base abutment (group 1) will have greater ΔE when compared to the lithium disilicate crown on titanium abutment with zirconia coping (group 2). The second hypothesis was the lithium disilicate crown on titanium base abutment (group 1) will have greater ΔE when compared to the high translucent multilayered zirconia crown on titanium base abutment (group 3). The final hypothesis was that the lithium disilicate crown on titanium base abutment with zirconia coping (group 2) will have greater ΔE than the high translucent multilayered zirconia on titanium base abutment (group 3).

The purpose to evaluate the above hypotheses was based on the expectation that in a clinical situation the color of a LT full contour lithium disilicate implant crown will be affected by the titanium base abutment more than the color of a HTML full contour zirconia implant crown. And with a design of HT zirconia coping, the effect from titanium base abutment to color of a LT lithium disilicate implant crown will be reduced.

The findings of this study were in agreement with a previous study conducted by Harada et al. who measured the translucency of UT, ST and HT Katana zirconia and LT e.max CAD.⁸¹ Among all groups, e-max CAD LT was the most translucent and the Katana UT was significantly more translucent than Katana ST and Katana HT when samples were 0.5mm thick. Katana ST and Katana UT were significantly more translucent than all Katana HT but less than e-max CAD LT when the samples were 1 mm in thickness. The results also coincided with the study done by Kwon et al. The translucency of e-max CAD LT and HT

and Katana in UTML and HT were compared in 1mm thickness.⁸² The e-max CAD HT had the highest translucency, followed by e-max CAD LT and Katana UTML, whereas Katana HT had the lowest translucency. However, the samples in the above studies were in form of discs rather than full contour crowns.

In terms of full contour crown sample in our study, the thickness of lithium disilicate crowns in group 1 are the same as zirconia crowns in group 3, with 2.2 mm thickness at the measurement level. However, the Lithium disilicate crowns in group 2 were different from the other two groups in order to leave space for the zirconia coping, which resulted in 1.4 mm at the measurement level. So, the color measurement results comparison was based on different protheses design considering both crown and abutment design rather than solely focusing on thickness of restorations.

The measurement point was set 3 mm above the gingival line at cervical area. The cervical area below 4.5 mm would potentially be influenced by the titanium background effect as the abutment was 5.5 mm in height with 2 mm gingival height and inserted 3 mm sub-gingivally. The crown thickness is usually thin in the cervical area compared to mid-third or coronal third area of a crown. The above situation made it challenging for the cervical area to have predictable white esthetics outcome compared to middle to coronal area of a full ceramic restoration.

The brand of ceramic can have influences on the final color of prostheses. Habib et al. found that ΔE recorded for the same porcelain shade from different brand of commercial zirconia materials are different.⁸³ Therefore prostheses fabricated from lithium disilicate and zirconia from different companies can have different colors outcomes even though categorized in same shade.

Vichi et al. found that color matching can be impacted with shade of tested objects. In his study 2009 showed differences in color between A2 porcelain disks and corresponding VITA shade tabs were closer (mean $\Delta E = 2.50$) than those recorded for shade A3 (mean $\Delta E = 3.84$) and shade A3.5 (mean $\Delta E = 3.94$) ($P < 0.05$).⁸⁴ In another study of his in 2012, it was found that the results with shade A3 were considerably worse than shades with A2 and A4.⁸⁴

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The Vitapan Classical shade guide system (Vita Zahnfabrik, Bad Sackingen, Germany) in the software was used as control group. It is one of the most popular used commercial shade guides in dentistry. It is based on the color frequency of natural teeth. The Vitapan 3D Master shade guide system (Vita Zahnfabrik, Bad Sackingen, Germany) is systematically arranged on the CIELCh color scale. The color replication ability of it was found to be better than that of the Vitapan Classical. Studies showed color reading with Vitapan 3D Master resulted in the lowest coverage errors than Vitapan Classical and has been reported to be more reliable.^{86, 87} However, the ΔE values and the examiners' scores were within the clinically acceptable range for both shade guides and the ceramic crowns fabricated with both shade guides had acceptable color matches.⁸⁸

There are two different thresholds for ΔE , the perceptibility threshold and acceptability threshold. Perceptibility is that how much color difference is considered perceivable to observers. The perceptibility threshold (PT) is the predicted color difference at which 50% of the dentist observers could perceive a color difference. Acceptability is how much color difference constitute an acceptable shade mismatch. The acceptability threshold (AT) is the predicted color difference at which 50% of the subjects would remake the restoration due to color mismatch, which means it is a clinically unacceptable color match.⁸⁹ According to a

systemic review done by Khashayar et al. , more than half of the studies defined PT as $\Delta E = 1$, and one third of the studies referred AT to $\Delta E = 3.7$ (ranging between 2.0 and 4.0).⁹⁰ My study results showed the maximal ΔE of group 2 and group 3 were within the acceptability threshold.

Clinical implication

Although further research is required, higher opacity ceramic such as Katana HTML or design of zirconia coping underneath lithium disilicate crowns may be considered for restoring implant prostheses with titanium metal abutment. The new prosthesis design used in group 2, with access holes both on zirconia abutments and crowns constituted screw-cementable prostheses. The design of zirconia coping and lithium disilicate crown could enhance the esthetics and overall treatment outcome and could be a prosthetic choice in the future. However, future studies are required before definitive clinical recommendations can be made.

Limitation of the study

There were several limitations in this study. Firstly, only one implant position was tested as the implant position can change the thickness of the prostheses thickness. Only one shade of ceramics was used to fabricate crowns. Moreover, only one type of zirconia material was used as the coping for titanium base abutment. Different shape of coping design in different translucency material should also be considered and evaluated.

Future study

Different of implant positions resembling different clinical scenarios should be evaluated since the thickness of prostheses will be significantly influenced by the implant position. The testing different ceramic materials from different brand and in different shade should be required. Other translucency of materials should also be evaluated and compared to provide more comprehensive understanding of knowledge and insight in this field.

CONCLUSION

Within the limitations of this study, the following conclusions can be drawn:

1. Mean ΔE of Lithium disilicate on titanium base abutment (group 1) was higher compared to Lithium disilicate on titanium and zirconia abutment (group 2).
2. Mean ΔE of Lithium disilicate on titanium base abutment (group 1) was higher compared to Zirconia on titanium base abutment (group 3)
3. Mean ΔE of Lithium disilicate on titanium and zirconia abutment (group 2) was higher compared to Zirconia on titanium base abutment (group 3)

APPENDIX A

Table 1. Descriptive Analysis for ΔE by combination of crown material, and abutment material (n=16 per group)

Group	Crown	Abutment	Mean	SD	Minimum	Maximum
1	E.max	Ti	3.44	0.27	3.01	3.97
2	E.max	Ti + Zirconia	2.60	0.24	2.29	2.99
3	Zirconia	Ti	2.07	0.10	1.91	2.23

The highest ΔE mean was recorded for group 1: Lithium disilicate crown on the titanium base abutment (3.44 ± 0.27), followed by group 2: Lithium disilicate crown on the titanium base abutment with zirconia coping (2.60 ± 0.24), whereas the lowest ΔE mean was recorded for group 3: HTML zirconia on the Titanium base abutment (2.07 ± 0.10). The means of all groups were significantly different ($p < 0.001$). The means of all groups were significantly different ($p < 0.001$). All pairwise comparisons were statistically significant ($p < 0.001$).

APPENDIX B

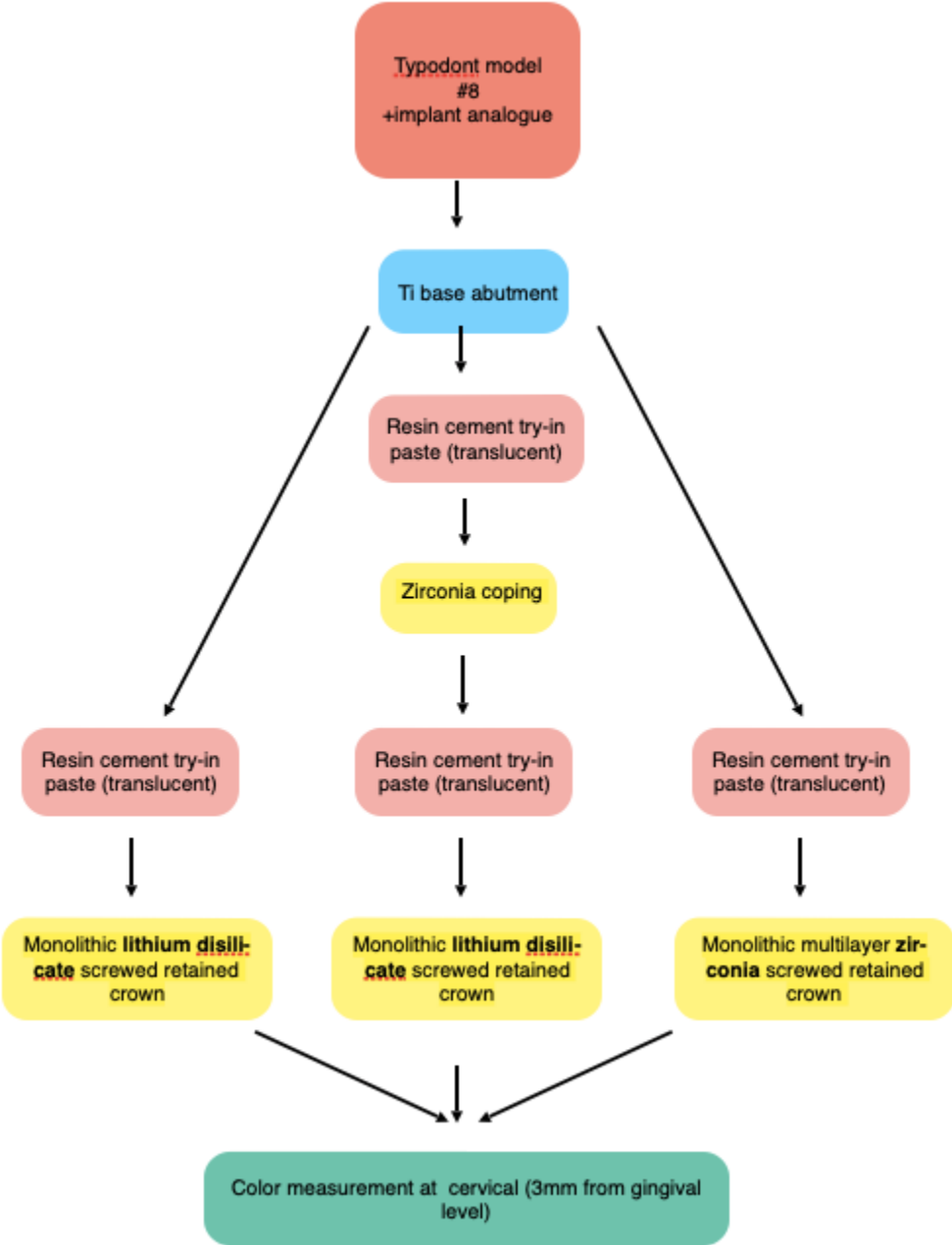


Figure 1. Study Design



Figure 2. Prepared typodont with 34.1 implant analogue in the position of #8



Figure 3. Scan body attached to typodont



Figure 4. 5.5 mm ti-base in relation to location marks



Figure 5. Crown in relation to location marks



Figure 6. Zirconia coping on titanium base abutment



Figure 7. Typodont positioned in the blackbox

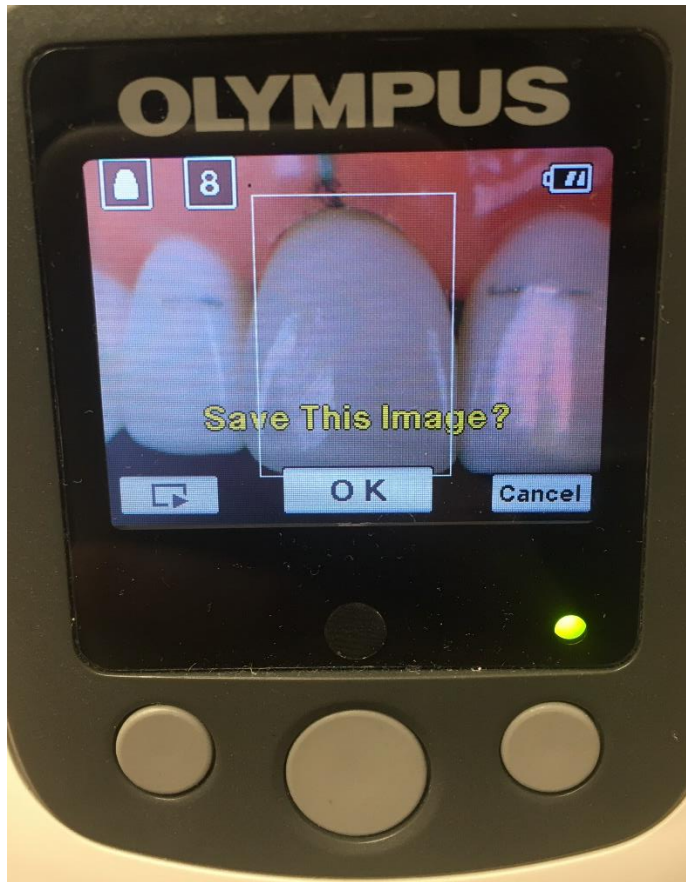


Figure 8. Capturing utilizing the coordinates of the spectrophotometer

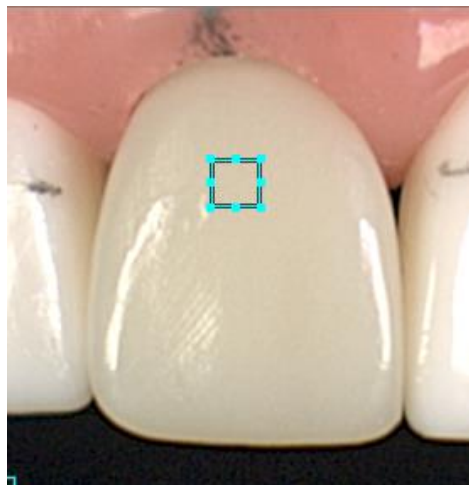


Figure 9. Screen shot of the Crystaleye software showing the location of measurements

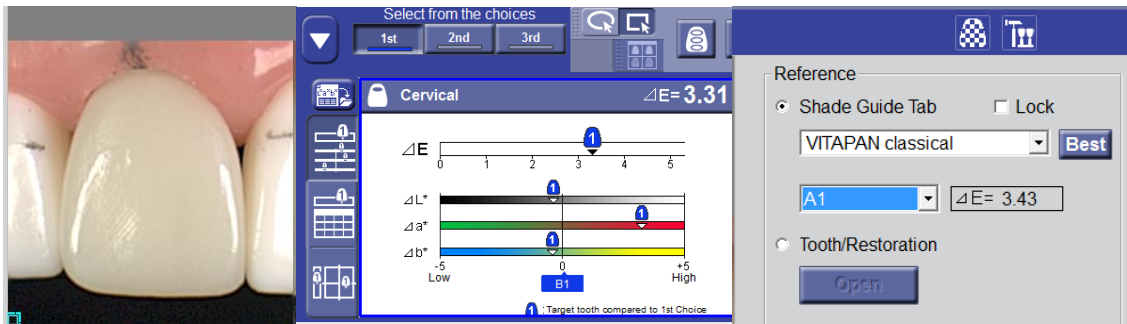


Figure 10. Screen shot of the Crystaleye software showing the measurements of ΔE

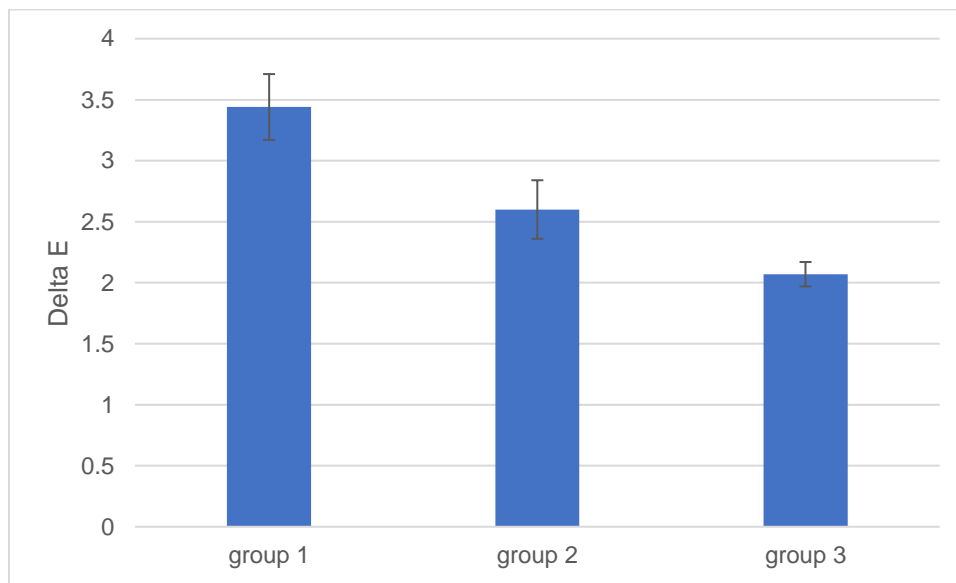


Figure 11. Bar graph illustration of the ΔE results of all 3 groups. The error bar in each bar represents the standard deviation.

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