The Influence of Core-Veneer Thickness and Translucency on Color of Lithium Disilicate

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ABSTRACT

Aim:

To compare three different techniques (layering, cutting-back and staining) of two translucencies (HT & LT) in terms of color differences for IPS e.maxPRess lithium disilicate glass ceramics shade A1.

Materials & Methods:

Based on a pilot study, n = 10 for the number of lithium disilicate glass ceramic discs per group was an appropriate sample size. 12mm diameter discs with 1.5mm different core & veneer thickness were fabricated for high-transparency (HT) and low-transparency (LT) e.maxPress shade A1. 12mm diameter with 4mm thickness Verse-temp shade A2 discs were used as a background. Six experimental groups were evaluated in terms of color differences: groups (HT5 & LT5) were 0.5 mm core + 1 mm veneer thickness; groups (HT10 & LT10) were 1 mm core + 0.5 mm veneer thickness; groups (HT15 & LT15) were 1.5 mm monolithic without receiving any veneer. Vita shade A1 was used as a reference group. A crystaleye spectrophotometer was used to measure the color differences. Two independent-samples t-tests were used for the comparison of the translucency at 1 mm & 1.5 mm core thicknesses. A nonparametric test (Mann-Whitney U) test was used for the comparison of the translucency at 0.5 mm core thickness. Non-parametric (Kruskal-Wallis) tests were used for the comparison of the thicknesses at each translucency, and Mann-Whitney U tests with Bonferroni correction were used as post-hoc tests.

Results:

Statistically significant differences were found among the tested groups ($P < 0.001$). The highest mean color difference (ΔE) was observed in the HT5 group, while the lowest ΔE

mean was observed in the LT15 group. For each translucency, 0.5 mm core thickness showed the highest ΔE. For each core thickness, the HT groups showed higher ΔE compared to the LT groups. The two independent-samples t-tests revealed a significant difference between the two translucencies ($p < 0.001$) at 1mm core and 1.5 mm core. The Mann-Whitney U test revealed a significant difference between the translucencies ($p < 0.001$) at 0.5 mm core. The Kruskal-Wallis test comparing the three thicknesses was significant ($p < 0.001$) at HT; all post-hoc tests were significant ($p \leq 0.004$). Similarly, at LT the Kruskal-Wallis test comparing the three thicknesses was significant ($p < 0.001$), and all post-hoc tests were significant ($p < 0.001$).

Conclusion:

Within the limitations of this study, the results reflected that the level of translucency and the different core-veneer thickness significantly influenced the color of lithium disilicate glass ceramic shade A1. Using the LT ingots decreased difference in color. Increasing veneer thickness and decreasing core thickness increased color differences. LT ingot was recommended to use even with slight color difference in background.

DEDICATION:

To my wife, Hassna Almutwah, for your love, patience, endless support, and for constantly pushing me forward.

To my kids, Haider, Nazer, Hassan and Batoul, I hope my encouragement to work harder, helps build a brighter future.

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LT: High Translucency.

LT: Low Translucency.

ΔE: Color difference.

HT15 group: High Translucency with 1.5 mm core without veneer group.

HT10 group: High Translucency with 1 mm core and 0.5 mm veneer group.

HT5 group: High Translucency with 0.5 mm core and 1 mm veneer group.

HT15 group: Low Translucency with 1.5 mm core without veneer group.

HT10 group: Low Translucency with 1 mm core and 0.5 mm veneer group.

HT5 group: Low Translucency with 0.5 mm core and 1 mm veneer group.

The Influence of Core-Veneer Thickness and Translucency on Color of Lithium Disilicate

Introduction

All ceramic systems provide a desirable esthetic outcome by allowing light transmission and penetration through the prosthesis and underlying tooth structure. [1] This creates a deep translucency similar to that of a natural tooth. In an attempt to achieve a perfect match to the adjacent natural teeth, porcelain veneers have been used widely because of their ability to create translucency. [1] Various core and veneer thicknesses with different translucencies are used in all-ceramic systems to obtain a natural appearance. Translucency, which gives this natural appearance, is essential, together with matching the shape and surface texture of the adjacent natural teeth. Occasionally, shade guides are used to achieve visual shade matching; however, these shade guides have limited colors by comparison to those of natural teeth. [1,2] Condensation techniques, firing temperatures, [1,3] and dentin layer thickness[1] are among the factors that affect the ability of a ceramic system to produce a good match with corresponding shade guides. [4-6]

Color assessment is a complex process that should be understood by the dental provider. According to the Munsell terms,[7] the color can be described by hue, value, and chroma. Hue is the descriptive term that enables one to distinguish between different families of color, for example, reds, blues, and greens. Value is the relative lightness and darkness, while chroma is the degree of color saturation or the strength of the color. Although dentin is the primary source of color, it is affected by the thickness and translucency of the overlying enamel. [7]

Brodbelt et al. [8] stated that translucency is the relative amount of light transmitted through the material, while Johnston et al. [9] defined it as the ability of a layer of colored substance to allow the appearance of an underlying background to show through. According to Cook and McAree, [10] O'Brien et al.[11] and Yu and Lee, [12] the translucency of the enamel and dentin is wavelength dependent. Brodbelt et al.[13]and Heffernan et al.[14] stated that the thickness of the material is a factor that affects translucency, while O'Keefe et al.[15] found that the thickness of a porcelain veneer was the primary factor affecting light transmission. The translucency of dental ceramics is affected by thickness, [1,8,9] the number of firings, luting agent, [1,16] substructure shade, [1,3,17] texture, [9,18,19] and illuminant. [9]

Recently, a high-strength lithium disilicate glass ceramic material (*IPS e.max Press*) has been used to fabricate anterior and posterior crowns because of its superior translucency. This translucency, in turn, aids in matching the color of the natural tooth. [20] However, in addition to translucency, opalescence and fluorescence must be considered, as these factors also affect proper color matching. [18,21] Different translucencies and opacities of the Press ingots are available in the *IPS e.max* system. The High Opacity (HO) and Medium Opacity (MO) ingots are suitable predominantly for the layering technique, while the Low Translucency (LT) and High Translucency (HT) ingots are used more commonly for the cut-back and staining technique (Ivoclar Vivadent, 2009). [22] The two kinds of translucency may be acquired based on the size and amount of the crystals. HT contains a small number of large lithium metasilicate crystals in the precrystallized stage compared with LT, which contains a large number of smaller crystals. [3,20] The translucency of lithium disilicate can have a negative effect when the underlying substructure color is poor, such as in a tooth treated with a root canal. [3] However, insufficient information is available about the effect of different thicknesses of the LT and HT cores layered on the color outcome.

The specific aim of this study was to evaluate the influence of the three different techniques of fabricating e.maxPress glass ceramics (layering, cut-back and staining) for the high translucency and the low translucency ingots shade A1 on the final color of the lithium disilicate glass ceramics.

Literature review

Light and color

There are several factors that affect our ability to achieve an accurate shade-matching outcome, including subjectivity, shade-matching tools, materials, methods, environments, and case condition. [23,24] This is why clinicians and technicians should consider color education and training as the first step in a process that will produce an enhanced esthetic outcome in any type of dental restoration.

Color theory

Three elements: light, a viewer, and an object must interact in order for color to be perceived. Every person views the same object differently depending on the condition of influencing factors, such as light, background, material shades and translucencies, and eye fatigue. [25,26] Color is perceived by a basic process in which light is emitted from a source and either reaches our eyes directly or strikes or passes through an object. If the light interacts with an object, the object may absorb some of the light. The wavelengths that are not absorbed will be reflected, transmitted, or emitted directly to the human receptor cells or devices, which then recognize the object as a specific color. [27]

In the 20th century, Munsell noted that each color has a logical relationship with all other colors. He established an orderly system (color wheel) for identifying every color accurately that includes the three dimensions of hue (synonymous with the term color), value (relative lightness or darkness) and chroma (saturation and purity of color). Translucency (the degree to which light is transmitted rather than absorbed or reflected), which is not addressed in Munsell's color analysis, should be added to these dimensions, as translucency has been considered the most critical factor for an esthetic dental restoration. [25,26]

Metamerism

The term Metamerism can be defined as the phenomenon in which two objects appear to match in color under one condition, but appear different under another. In the dental office, for example, metamerism[26] occurs when a crown is matched to the natural teeth under fluorescent light, but when viewed under color-corrected or incandescent light, they will not appear to match. [25]

Color blindness

A person who has trouble seeing red, green, blue, or mixtures of these colors suffers from color blindness, although "color vision problem" is the preferred term. Cone cells located in the retina allow color perception, and while most people with color blindness can see some colors, they have a deficiency in or absence of one or more of the three kinds of photosensitive pigments that enable a person to detect red, green, and blue. The color vision problem causes an inability to discriminate hue, lightness, and saturation. [28]

Shade guides

In 1931, Clark reported that shade selection for direct and indirect dental restorations has always been a challenge for clinicians. [29] The Munsell color system[7] is the oldest color order system and has been used in dentistry to define color in terms of value, hue, and chroma. [30] Each shade guide system varies to some degree. Clark's Tooth Color Guide has 60 tabs, while Hayashi's guide has 125 paper tabs. Both are complex and inapplicable. In 1960, the Vita Lumin Vacuum shade guide was developed as a simplified system. In subsequent years, the shade guides of Chromascop, Vintage Halo and Bioform were introduced to the market. However, many studies have pointed out that these shade guide systems are inadequate to cover the spectrum of color in natural teeth, and the shade tabs are not distributed in the color space logically or systematically. In the late 1990s, an instrument-based color measurement, the ShadeScan system (Cortex Machina, Montreal, Canada), was introduced to the market. This was the first attempt to develop a shade analysis system for complete tooth surface measurement. [29] The commercial shade guide-matching system used most commonly is Vitapan Classical (Vita Zahnfabrik, Bad Sackingen, Germany). [30,31]

Instruments for clinical Shade-matching

In addition to the instruments that are used today (spectrophotometers, colorimeters and imaging systems), there are several commercial products that are no longer available or have limited availability in the market. These include Chromascan (Sterngold, Stamford, CT, USA), Dental Color Analyzer (Wolf Industries, Vancouver, Canada), Identacolor II (Identa, Holbaek, Denmark), Digital Shade Guide DSG4 (A. Reith, Schorndorf, Germany), Ikam (Metalor Technologies, Attleboro, MA, USA), ShadeEye NCC Chroma Meter (Shofu Dental, Menlo Park, CA, USA), Beyond Insight Shade Taking Device (Beyond Dental & Health, Beijing, China), Shadescan (Cynovad, Montreal, Canada) and Vita Easyshade (Vita Zahnfabrik, Bad Sackingen, Germany). [29]

Spectrophotometers

Paul et al reported that the spectrophotometer is the most accurate, useful, and flexible instrument for color matching in dentistry. [32] It contains a source of optical radiation, a means of dispersing light, an optical system for measurement, a detector, and a method of converting light obtained into a signal that can be analyzed. [29] Lagouvardos et al.[33] stated that the data obtained from spectrophotometers convert to a shade tab equivalent. Paul et al.[34]

found that spectrophotometers offered a 33% increase in accuracy when compared with observations made by the naked eye.

Crystaleye spectrophotometric system

There are several commercially available brands of spectrophotometers, including: Crystaleye (Olympus, Tokyo, Japan), which is an automated color shade-matching device that combines the benefits of a traditional spectrophotometer with digital photography. The Crystaleye device uses tooth shades from Vitapan Classical Shade Guide, Vita System 3D-Master Tooth Guide, Ivoclar Vivadent Chromascop, Noritake Shade Guide, and Vintage Halo NCC. The spectrophotometer captures an image of the target tooth, and the software matches the shade of a patient's tooth color with the closest shade available in the computerized reference database. Da Silva et al.[35] reported that this product allows providers to match tooth shade and color more accurately and simply compared with the traditional visual matching. Two metal ceramic maxillary central crowns have been fabricated for 36 patients using two shade-matching techniques, conventional visual matching (written prescription) using three shade guide systems, and an instrument-based color-matching technique using a Crystaleye spectrophotometric system. After calculating the color differences, the results of the mean ΔE values of crowns matched with the spectrophotometer were significantly lower than were those using conventional techniques. The result of the examiners was 22% of metal ceramic crowns fabricated by the conventional visual matching (8 out of 36) were acceptable level. However, 77% of crowns (28 out of 36) were acceptable using Crystaleye spectrophotometer. They concluded Crystaleye spectrophotometer could improve the clinical color match 12.5 times than the conventional way.

Chen et al.[36]also evaluated the reliability and accuracy of the Crystaleye spectrophotometer system. Four shade-guides have been measured (VITA Classical, VITA 3D-Master, Chromascop and Vintage Halo NCC) with Crystaleye spectrophotometer. The shade-matching results and the CIE L*a*b* values were analyzed. The range in reliability was 88.81% to 98.97%, and 0.13 to 0.24 ΔE units, while the range in accuracy was 44.05% to 91.25%, and 1.03 to 1.89 ΔE units.

Odaira at el. evaluated the clinical performance of the Crystaleye spectrophotometer by comparison to the CAS-ID1and MSC-2000.[37] The data from the three spectrophotometers were not significantly different. Color measurements with the Crystaleye spectrophotometer were repeated 10 times. The color difference (ΔE) between the first and tenth measurements was 0.6 units. The Crystaleye spectrophotometer was used to measure the color differences under two conditions (light and dark). The ΔE between light and dark conditions was 0.9 units. There are several commercial spectrophotometer devices that are small, portable, and cordless, such as Vita Easyshade Compact (Vita Zahnfabrik, Bad Sackingen, Germany). Shade-X (X-Rite, Grandville, MI) is also a cordless spectrophotometer with a 3-mm diameter probe. SpectroShade Micro (MHT Optic Research, Niederhasli, Switzerland) is an imaging spectrophotometer that incorporates a digital camera/LED spectrophotometer combination.

Colorimeters

Colorimeters filter light in red, green, and blue areas of the visible spectrum. Kim-Pusateri et al[38] used four shade-matching devices and made color measurements with three commercial shade guides (Vitapan Classical, Vitapan 3D-Master, and Chromascop). They concluded that most devices had similarly high reliability (over 96%). However, differences in accuracy were seen in most device comparisons. It has been stated that colorimeters do not register spectral reflectance and can be less accurate than spectrophotometers.

Examples of commercially available colorimeters are ShadeVision (X-Rite, Grandville, MI), SpectroShade, Vita Easyshade, and ShadeScan.

Digital cameras and imaging systems

Digital cameras represent the most basic approach to electronic shade measurement; however, Blaes[39] reported that this system still requires a certain degree of subjectivity. Clear Match (Smart Technology, Hood River, OR) is a software system that uses high-resolution digital images and compares shades over the entire tooth to known reference shades.

Visual vs. instrumental findings

Visual color matching is subjective, and is influenced by a variety of factors, including variations in the type and quality of light, [40,41] the presence of color blindness, and/or color perception defects, differences in gender, [42,43] and the experience of the evaluators. [44] Fani et al.[45] found better results in approximately 47% of the cases when a spectrophotometer was used rather than a visual method. These results were in agreement with independent studies reported by Da Silva et al. [35]and Gehrke et al. [46]

Classification of dental ceramics

There are only three main divisions in the spectrum of dental ceramics: (1) predominantly glassy materials, (2) particle-filled glasses, and (3) polycrystalline ceramics. [47]

(1) Predominantly glassy ceramics

Glasses in dental ceramics are derived from the silica (silicon oxide) and alumina (aluminum oxide)-based mineral, feldspar. These feldspathic porcelains belong to a family called aluminosilicate glasses. [48]

(2) Particle-filled glasses

Filler particles are added to the base glass composition to improve mechanical properties and to control optical effects, such as opalescence, color, and opacity. These fillers are usually crystalline, but can also be particles of glass with a higher melting point. The first fillers to be used in dental ceramics contained particles of a crystalline mineral called leucite.[49] This filler was added to create porcelains that could be fired onto metal substructures successfully.

(3) Glass-ceramics (Subset of particle-filled glasses)

Crystalline filler particles can be added to the glass mechanically.[47] The material Dicor (Dentsply), the first commercial glass ceramic available for fixed prostheses, contained filler particles of a type of crystalline mica at 55% volume. More recently, a glass-ceramic containing 70% volume crystalline lithium disilicate filler has been commercialized for dental use (Empress 2, Ivoclar Vivadent).[47]

(4) Polycrystalline ceramics

Polycrystalline ceramics have no glassy components; all of the atoms are packed densely into a regular network that is very difficult to crack. Polycrystalline ceramics are generally much stronger than glassy ceramics.[47]

Current ceramic materials and systems with clinical recommendations

Glass ceramics

IPS Empress (Ivoclar Vivadent) is a lithium-disilicate glass ceramic (SiO_2 -Li_2O) that is fabricated through a combination of the lost-wax and heat-pressed techniques.[50] The *IPS Empress* was the first generation of heat-pressed ceramics. It is 35-45% leucite-reinforced glass ceramic in the crystalline phase (SiO_2 -Al_2O_3 -K_2O) and, due to its strength, is limited in use to single unit anterior restorations. The second generation is the *IPS*

Empress 2 (Ivoclar Vivadent), which contains 65% lithium disilicate by volume and, as the main crystalline phase has a flexural strength three times greater than the *IPS Empress*, it can be used for anterior 3-unit FPDs, and can extend to the second premolar. [51,52] The framework is veneered with a fluoroapatite-based veneering porcelain (IPS Eris, Ivoclar Vivadent).

IPS e.max Press (Ivoclar Vivadent) was introduced in 2005 as a press-ceramic material that improved on the performance of *IPS Empress 2*. It is also a lithium-disilicate pressed glass ceramic and is composed of quartz, lithium dioxide, phosphor oxide, alumina, potassium oxide, and other components. The crystals of the *IPS e.max Press* and *IPS e.max CAD* are the same in composition (70% crystalline lithium disilicate). However, the size and length of these crystals differ, which affects their material properties. While the coefficient of thermal expansion (CTE), modulus of elasticity, and chemical solubility remain the same, the flexural strength and fracture toughness are slightly higher for the *IPS e.max Press* material. [53] The *IPS e.max* system offers different shades and opacities of Press ingots. The more opaque HO and MO ingots are predominantly suitable for the layering technique, while the more translucent LT and HT ingots are used for the cut-back and staining techniques (Ivoclar Vivadent, 2009). The two types of translucency may be acquired based on the size and number of crystals. HT ingots contain a small number of large lithium metasilicate crystals in the precrystallized stage, while the LT ingots contain a larger number of smaller crystals.

IPS e.max Press CAD (Ivoclar Vivadent) is available in blue ceramic blocks, and requires two-stage processing. The first is the intermediate crystallization phase, which contains approximately 40% lithium meta-silicate crystals by volume. This phase provides excellent processing properties for milling, without excessive bur wear. The second is the heat-treating stage. After the milling process, the meta-silicate phase is dissolved completely, and the lithium disilicate is crystallized in a porcelain furnace at 840-850^{0}C.

IPS Pro CAD (Ivoclar Vivadent) is a leucite-reinforced ceramic similar to *IPS Empress*, but with a finer particle size.

Vita Mark II (VITA Zahnfabrik) is a machinable feldspathic porcelain that consists of SiO2 (60-64%) and Al2 O3 (20-23%).[54] *Vita TriLuxe Bloc* (VITA Zahnfabrik) was designed to create a 3-D layered structure. It is a multicolored ceramic block that overcomes the esthetic disadvantages of a monochromatic restoration and mimics the optical effects of natural teeth. The inner third includes an opaque layer, while the middle third has a neutral layer, and the outer third is more translucent.

Chaiyabutr et al. [55] tested the outcome of three factors. Four different colors of prepared tooth (light, medium light, medium dark, and dark), two cement (Variolink II) colors (translucent and opaque), and four ceramic thicknesses (1.0 mm, 1.5 mm, 2.0 mm, and 2.5 mm) on the color of CAD/CAM lithium disilicate glass ceramic reinforced monolithic crowns (*IPS e.max CAD LT*). They found that the influence of these three variables produced significant differences in the crowns' color outcomes. For example, when the ceramic thickness was increased, the ΔE value decreased; the dark-colored prepared tooth presented the highest ΔE values compared to the other variables. Moreover, when the crowns were cemented using opaque cement, the ΔE values decreased slightly.

Alumina-based ceramics

In-Ceram Alumina (VITA Zahnfabrik) was the first all-ceramic system available for single-unit restorations and 3-unit anterior FPDs. It has a high strength ceramic core and the coping is veneered with feldspathic porcelain. [56] *In-Ceram Spinell* (VITA Zahnfabrik) is an alternative to the non-esthetic opaque core of *In-Ceram Alumina*. It contains magnesia and alumina ($MgAl_2O_4$) to produce greater translucency; however, its flexural strength is less than that of *In-Ceram Alumina*. *In-Ceram Zirconia* (VITA Zahnfabrik) is also a modification of the original *In-Ceram Alumina* system, with the addition of 35% partially stabilized zirconia oxide to strengthen the ceramic. [57]

Procera (Nobel Biocare) was developed with copings that contain 99.9% high purity aluminum oxide. It is combined with a low-fusing veneering porcelain and has the highest strength of the alumina-based materials, exceeded only by zirconia.

Zirconia-based ceramics

Zirconia is a polymorphic material that occurs in three forms. At its melting point of 2680 ^{0}C, it has a cubic structure, which transforms into a tetragonal phase below 2370 ^{0}C. [58,59]The tetragonal-to-monoclinic phase transformation occurs below 1170 ^{0}C and is accompanied by a 3-5% volume expansion that causes high internal stresses; thus, Yttrium-oxide (Y_2O_3) 3% mol% is added to pure zirconia to control the volume expansion and to stabilize it in the tetragonal phase at room temperature.

Porcelain veneers

Porcelain veneers have been used widely in esthetic dental dentistry for many years. Some authors, such as Calamia[22] and Shaini et al.[60] reported that the success of porcelain veneers is due to the durable bond between two materials with similar elastic moduli, porcelain and enamel.

Thicknesses of 0.3 mm have been used for minimally invasive veneers, [61,62] whereas conventional porcelain veneers generally range from 0.3 to 1.0 mm in thickness. [63] Excellent clinical outcomes and high survival rates are the advantages of conventional porcelain veneers. [64,65] Shaini et al.[60] evaluated the operator's experience and its effect on the clinical success of porcelain veneers. They found that higher failure rates (39%) were observed when the restoration was performed by inexperienced clinicians compared to those placed by experienced clinicians (22%).

Friedman[66] reported that a low failure rate of 7% was found for veneers placed in private practice over a period of 15 years. These results are in agreement with Dumfahrt and Schaffer, who reported a 90% success for veneers after 1 to 10 years of service. [67] A low failure rate of 5% at 5 years, and less than 10% at 10 years was also reported by Della Bona and Kelly[68] in their systematic review. Layton and Walton[69] also found a high success rate for veneers after specific periods of time in service. The success rate was 96% at 5-6 years, 93% at 10-11 years, 91% at 12-13 years, and 73% at 15-16 years.

Alghazzawi et al.[65] investigated the color effect of trial insertion paste (TP), composite resin abutment (CRA), and veneer regions on the optical properties of feldspathic porcelain (FP), yttria-stabilized zirconia (Y-TZP), and *IPS e.max CAD HT* (IEC) veneers. The author reported that the underlying color of the tested trial insertion pastes caused a color change of $\Delta E > 3.7$, for different regions for *IPS e.max CAD* and for feldspathic laminate veneers, while the yttria-stabilized zirconia laminate veneers with relative opaqueness were not affected significantly by the color of the trial insertion paste or the composite resin abutment color. No significant effect of the color of the composite resin abutment was observed on the overall color of any of the laminate veneers. The yttria-stabilized zirconia laminate veneers were brighter, more yellowish, and more reddish than were the *IPS e.max CAD* and feldspathic porcelain laminate veneers, and the *IPS e.max CAD* laminate veneers demonstrated the same brightness as feldspathic porcelain laminate veneers, but were more greenish and bluish. [65]

Feldspathic porcelains

For many years, conventional feldspathic porcelains have been considered the material of choice to provide optimal esthetic results for porcelain veneers. The feldspathic porcelain is based on feldspar and encompasses a tectosilicate mineral, feldspar, quartz, or kaolin. These feldspathic ceramic materials have excellent aesthetic properties. [70] They can be used to fabricate veneers, inlays/overlays, and single anterior and posterior crowns. [71,72] After using a combination of aluminum oxide airborne abrasion followed by hydrofluoric acid etching [73] and a silane coupling agent, [74,75] feldspathic ceramics can be bonded to the tooth structure.

Recently, advances in dental ceramics and biomaterials have introduced porcelains with greater strength; however, these materials demonstrate reduced translucency. [76] A high strength lithium disilicate glass ceramic (*IPS e.max Press*) allowed the fabrication of non-veneering anterior and posterior crowns and the fabrication of thin veneers. [58,77] Compared to *IPS Empress 2*, *IPS e.max Press* is based on the same material, but has higher translucency, [59,77,78]strength, and toughness. Etman et al.[58] compared the clinical performance of *IPS e.max Press*, an alumina-coping-based ceramic (*Procera AllCeram*), and a metal ceramic. The crowns were assessed over 3 years. The results showed that *IPS e.max Press* posterior crowns had a clinical performance similar to *Procera AllCeram* and metal ceramic crowns. Chu[29] showed that feldspathic porcelain is the most translucent material compared to *Procera*, *Empress 2*, and *Vitadur Alpha*. Heffernan et al.[79] also came to a similar conclusion when comparing the translucency of *Vitadur Alpha*, *Empress*, *In-Ceram Spinell*, *Empress 2*, *Procera*, *In-Ceram Alumina*, and *In-Ceram Zirconia*.

CAD/CAM glass ceramics

Dental ceramics are based primarily on silicon (Si), usually in the form of silicon dioxide (SiO2) or various silicates. These ceramic restorations can be produced by either traditional laboratory methods or CAD/CAM machination.[80,81] The time required, technique sensitivity, and unpredictability are some disadvantages of conventional methods,[80] while CAD/CAM can reduce the fabrication time of high strength ceramics such as *InCeramTM* by up to 90%.

CAD/CAM-compatible feldspathic ceramics

In 1985, the first CAD/CAM inlay was made, using a ceramic block containing fine grain feldspathic ceramic. Otto reported that the success rate of these CAD/CAM inlays was 90.4%. He evaluated 200 Cerec inlays and onlays placed in private practice over 10 years. A total of 15 (8%) failures were found in 11 patients. The reasons for the failures included ceramic fractures, tooth fractures, caries, and endodontic problems.[82]

VitaTM Mark II

In 1991, *VitaTM Mark II* (Vita Zahnfabrik, Bad Sackingen, Germany) was introduced and demonstrated improved mechanical properties. Its flexural strength ranged from 100 MPa to 160 MPa after glazing.[83] The composition of *VitaTM Mark II* blocks is similar to the conventional feldspathic ceramic, but is produced by a different process. *VitaTM Mark II* is monochromatic, but it is available in multiple shades. The newer *VitablocsTM* (Vita Zahnfabrik, Bad Sackingen, Germany) contains multi-shade layers and offers a slope of color and translucency.[83]

CAD/CAM and Mica-based ceramics

DicorTM (Dentsply, York, USA) is a mica-based glass ceramic that is no longer available on the market. The machinable version, *DicorTM MGC*, was composed of up to 70% of a crystalline phase, as compared to the 45% crystalline content of the laboratory ceramic, *DicorTM*, which may explain the reported increased flexural strength to about 229 MPa. [84] Pallesen et al.[85] and Gladys et al.[86] reported that *DicorTM MGC* and *VitaTM* bBlocks were very similar in clinical performance.

CAD/CAM with leucite-reinforced ceramics

These ceramics were introduced in 2006. They are a leucite-reinforced ceramic that contains approximately 45% leucite with a finer particle size of about 1–5 um and a flexural strength of about 160 MPa. It can be used for single tooth restorations and is available in HT (*EmpressTM CAD HT*), LT (*EmpressTM CAD LT*) and polychromatic (*EmpressTM CAD Multi*) blocks. After milling, the restoration can be stained and glazed. [83]

CAD/CAM milling lithium disilicate reinforced ceramics

Lithium disilicate (Li2SiO5) ceramic has a flexural strength ranging from 350 MPa to 450 MPa. The chair-side monolithic restorative material e.max CAD (Ivoclar Vivadent) was introduced in 2006. It is available in different shades and translucencies and is supplied in a precrystallized blue state. After being milled, the restoration is recrystallized in a chair-side ceramic oven at 850 ^{0}C. During this heat treatment, the metasilicates dissolve, lithium disilicate crystallizes, and the ceramic is glazed at the same time. The block also changes from blue to the chosen shade and translucency. Reich evaluated 41 posterior crowns made of full-contour lithium disilicate in a clinical study. After two years, one crown exhibited secondary caries and two received root canal treatment. [87] Fasbinder et al fabricated 62 monolithic lithium disilicate crowns and their performance was high after two years of clinical service. [88] The survival rate for the two studies ranged from 97.4% to 100%.

CAD/CAM and glass-infiltrated alumina and zirconia ceramics

The *VitaTM InCeram* groups of ceramics are glass-infiltrated ceramics. In 2006, Giordano reported the flexural strength for *InCeramTM Alumina*, *Spinell* and *Zirconia* were 450–600 MPa, 350 MPa, and 700 MPa, respectively. The five-year survival rate of CAD/CAM *InCeramTM Spinell* was reported to range from 91.7% to 100% [89] while it was 92% for CAD/CAM *InCeramTM Alumina.* [90]

Awliya et al.[91] reported that acid etchants had no beneficial effects on aluminum trioxide. Glass ionomer cement has been suggested for luting; [92] however, air abrasion with 50 μm aluminium trioxide[74,75] and a silane coupling agent [74] have been suggested to be effective. [91,93] Chai et al.[94]reported that the bonding of *InCeramTM Zirconia* can be increased significantly when the surface is treated with a tribochemical silica coating followed by the use of a silane coupling agent.

CAD/CAM compatible polycrystalline alumina and zirconia

Polycrystalline ceramics have no glassy matrix and all the crystals are packed densely and then sintered. [95] These have excellent mechanical properties; however, polycrystalline ceramic is opaque, which limits its esthetic outcome. [95]

Alumina-based polycrystalline ceramics

ProceraTM AllCeram (Nobel Biocare, Goteborg, Sweden) was introduced in 1993. It contains more than 99.9% alumina. Andersson et al.[96] and Zeng et al.[97] reported that its flexural strength is approximately 600 MPa. Odman et al.[98] and Fradeani et al.[99] found that the survival rates of *ProceraTM AllCeram* anterior and posterior crowns were approximately

97% and 93.5% after 5 and 10 years, respectively. Limkangwalmongkol et al.[100] concluded that the marginal fit of this ceramic restoration is between 60 and 80 µm.

Edge-loss phenomenon

Edge-loss is a phenomenon that occurs with translucent materials when the light within the sample is scattered to the edges without being absorbed and, as a result, this lost light is not perceived by the sensor of the spectrophotometer, causing decreased accuracy in color measurements. [101,102] According to Johnston et al.[9] the degree of edge-loss is dependent on several variables, including the beam size of the illumination, direction of the illumination, observation geometry of the optical device, optical characteristics and thickness of the translucent layer, and the reflectance of the opaque backing.

Bolt et al. [102] reported that the edge-loss was affected by the window size, as well as the absorption and scattering properties of the sample. The edge-loss decreased significantly when the spectrophotometer's window size was increased. However, the window size is limited by the dimension and shape of the specimens.

Another way to minimize and control the edge-loss is to ensure that the specimen is in optical contact with the backing, which can be achieved by adding an interface layer of aqueous solution between the specimen and the backing to seal the air space. Different authors have used different solutions. Johnston et al.[9] Davis,[103] and Ragain and Johnston[101] used a sucrose solution. Ahn and Lee [104] and Segui et al.[105] used optical fluid, while Molenaar et al.[106] used a glycerol and water solution and Liu et al.[107] used immersion oil. Moreover, Johnston et al.[9] used a stainless steel spectrophotometer specimen holder to control the edge-loss effect. This device surrounds the edges of the samples in such a way that they are in optical contact with the polished aluminum holder and thus maintain optical contact with the backing.

Evaluation of visual color thresholds

Various color difference formulas have been reported in the dental literature; however, there is poor agreement among them. Color differences with corresponding ΔE values lower than 3.3 are acceptable. [108] Kuehni and Marcus found that the average CIELAB color difference required for 50% of 63 observers (experienced and industrial color matchers) to perceive a color difference was ΔE = 1 and there was no significant difference between perceptibility and acceptability judgments. [109] Seghi et al. evaluated color perceptibility in a group of 27 dental professional observers (23 dentists and 4 dental technicians) using translucent color porcelain disks. They suggested that color differences of ΔE equal to or greater than 2 CIELAB units were detectable. [105] Ragain and Johnston also conducted a study with porcelain discs and found that the average of the color difference acceptability was ΔE = 2.72 units. [109] Ruyter et al estimated color difference acceptability among sample pairs of dental composite resin and found that 50% of 12 observers (6 dental professionals and 6 chemists) considered that a ΔE of approximately 3.3 units was unacceptable. [108] Douglas and Brewer measured the thresholds of the a* and b* value directions of CIELAB color space. A group of dental providers was then asked to judge the color differences in PFM crowns. The results were 1.1 and 2.1 ΔE in the a* and b* directions, respectively, which were considered to be an acceptable range. However, both Douglas and Brewer used an instrument that exhibited edge loss, so the accuracy of the color difference measurement may contain significant error. [109,110] Vichi et al. [111] reported that ΔE values of less than 1 unit were not detectable to the human eye; 1< ΔE <3.3 were considered detectable by skilled clinicians, but clinically acceptable; ΔE values greater than 3.3 were noticeable to untrained observers and were considered unacceptable. Douglas et al. [112] reported that $\Delta E = 2.6$ is perceptible and $\Delta E = 5.5$ is acceptable. Ishikawa-Nagai [28] reported that a $\Delta E = 1.6$ is detectable by the human eye. [27] This study followed the literature and, with reference to the ceramic material, the following pattern was used: values of $\Delta E < 1$ were regarded as not appreciable to the human eye. Values between $1 < \Delta E < 3.3$ were considered appreciable to the unskilled, but clinically acceptable. Values of $\Delta E > 3.3$ were considered unacceptable clinically.

Only ceramic shade A1 was used.

Aim and hypothesis

Aims:

The specific goal of this study was to compare the color differences of lithium disilicate using three combinations of core and veneer thicknesses for both HT and LT (0.5 mm core with 1 mm veneer, 1 mm core with 0.5 mm veneer and 1.5 mm monolithic lithium disilicate without veneer).

Hypotheses:

- Ceramic discs with a thick layer of veneer will show a greater difference in color than other groups.
- LT groups will show less difference in color than HT groups.

Clinical Significance:

- The results of this study may help providers evaluate the influence of the different veneer-core thicknesses on the color differences of the lithium disilicate and to determine how much thickness they need for cut-back.

- The results of this study may help providers determine what kind of ingot they should select according to the clinical situation (HT or LT).

Research Design

Variables:

Translucency and the combination of core and veneer thickness were the two variables tested in this study. Translucency was divided into HT and LT, while the core and veneer thicknesses were divided into 3 groups:

- 0.5mm core with 1mm veneer.
- 1mm core with 0.5mm veneer.
- 1.5 mm core without veneer.

Materials and methods

Sample size calculation

A power calculation was conducted using nQuery Advisor (Version 7.0). Based on results from a pilot study, a sample size of n = 10 per group was adequate to obtain a Type I error rate of 5%, a power greater than 99% for comparing the thicknesses, and a power greater than 99% for comparing the translucencies.

Experimental groups

Lithium disilicate ceramic discs 12 mm in diameter and 1.5 mm thick in shade A1 (*IPS e.max Press*, Ivoclar Vivadent, Schaan, Liechtenstein) were fabricated. The discs were divided into two main groups: HT and LT. Group HT discs had a HT ingot core (HTA1) and group LT discs had a LT ingot core (LTA1). These two main groups each had three subgroups with different core and veneering porcelain thicknesses, resulting in six test groups. HT5 and LT5 subgroups had 0.5 mm mm core + 1 mm veneer thicknesses; HT10 and LT10 subgroups had 1 mm core + 0.5 mm veneer thicknesses; HT15 and LT15 subgroups had monolithic lithium disilicate discs (i.e., 1.5 mm core, and no veneer) (Figure22).

Fabrication of digital replica of wax discs

Three digital replicas with three different thickness designs (1.46mm, 9.96mm and 4.97mm) were created using 123D Design (Figure 1). Exocad Dental CAD software (Exocad GmbH, Darmstadt, Germany) was utilized to convert the 3 digital replicas to STL files (Figure 2). These three files were used to fabricate 12 mm wax disc patterns with three different thicknesses. A TizianMT Cut 5 CAD/CAM milling machine (Schitz, Dental Group, Germany) (Figure 3) was used to mill 20 mm wax blanks (YETI Dental digitalline, Engen, Germany). Three different wax pattern discs thicknesses were created: 0.5 mm, 1.00 mm and 1.5 mm (Figure 4).

Fabrication of *IPS e.max Press* specimens

All the *IPS e.max Press* discs were fabricated by the lost wax and heat-press technique according to the manufacturer's recommendations. A 4mm long, wax sprue was attached close to the edge of each wax pattern disc at an inclination between 45^0 and 60^0 (Figure 5). Wax discs were invested in the 200g-silicone investment ring, with a distance of at least 10 mm between the discs and the ring, and a distance of at least 3mm between each disc. The maximum height of the discs and sprues were not exceeding 16 mm. One small *IPS e.max Press* ingot was used to press each ring. All discs were fabricated with shade A1 in the

Vita Shade Guide (Vita Zahnfabrik). Investing was carried out with the IPS PressVEST Speed investment system according to its specific instructions. 200 grams of IPS PressVEST Speed powder was mixed with 32 mL of IPS PressVEST Speed liquid and 22 mL of distilled water. Initially, this was mixed manually for approximately 30 seconds to incorporate all the powder in the liquid, and then a mechanical vacuum was used to mix the investment materials for an additional 60 seconds. The investment materials were poured into the silicone investment ring with slight vibration of the ring on a dental vibrator (Figure 6). The investment materials were allowed to bench-set in the pressure-pot for 30 minutes (Figure 7). After bench setting, the silicone ring and the two plastic bases were removed.

The investment ring was placed in a burnout furnace at 1562^0 F for 60 minutes after the Programat EP 5000 (Ivoclar Vivadent AG, Schaan, Liechtenstein) press furnace was used to ensure preheating. The press program for *IPS e.max Press* and the 200 g investment ring was selected according to the ingot type (HT or LT). When the investment ring preheating cycle was completed, the ring was removed from the furnace. A cold *IPS e.max Press* ingot of shade A1 was placed in the hot investment ring, along with a cold IPS Alox Plunger coated with IPS Alox Plunger Separator. The investment ring, ingot, and plunger were placed in the center of the hot press furnace (Figure 8). The previously selected program was started. At the end of the program cycle, the investment ring was removed from the furnace and placed on a metal grid to cool evenly at room temperature. When the investment ring was completely cold, it was divested. The length of the Alox plunger was used to estimate the end of the sprues and was recovered by sectioning the investment ring at the appropriate level with a separating disk. Divestment was carried out with glass beads at 4 bars (60 psi) pressure (Figure 9). The pressed samples were immersed into *IPS e.max Press* InvexLiquid and cleaned ultrasonically for 15 minutes to remove the reaction layer. The white reaction layer formed on the pressed samples after immersion in the liquid was removed with type 100 Al_2O_3 at 2 bars (30 psi) pressure. The sprues were cut with a diamond disc. The sprue's area was smoothed with a diamond bur with water coolant. The specimens were finished. Each thickness of the specimen was checked using a digital caliper (Dentaguage 1, Erskine Dental, Marina Del Rey, CA) (Figure 10) to ensure that the specimens' thickness had not deviated from certain thicknesses (0.5 mm, 1 mm and 1.5 mm). Any deviation was adjusted by scratching specimens with sand paper (Figures 11-12).

Veneering application

Conventional veneering ceramic (*IPS e.max Ceram*, Ivoclar Vivadent, Schaan, Liechtenstein) was applied on the 0.5 mm and 1 mm cores. Groups HT5 and LT5 received a 1 mm veneer thickness, while groups HT10 and LT10 received a 0.5 mm veneer thickness. No veneering ceramic was added to groups HT15 and LT15.

Distilled water was mixed with *IPS e.max Ceram* powder, shade IT1, to create a creamy mixture. The mixture thickness specified was applied over the specimen. Silicon was created to help in controlling veneer thickness (Figure 13). The specimen was then placed in the porcelain furnace (Progromat P300), and the *IPS e.max Press* layering technique program was run (Table 3) (Figure 14). The number of firing was standardized to avoid the effect of the number of firing cycles on the material color, each specimen was fired twice..

The porcelain furnace was calibrated before firing the specimens (Figure 15). Each specimen`s thickness was checked again using a digital caliper (Dentaguage 1, Erskine Dental, Marina Del Rey, CA) to ensure that it had not deviated from 1.5 mm ($\pm$0.02). A layer of spread glaze material (*IPS e.max Ceram* Glaze Paste) was spread on one side of each specimen. The glaze firing was conducted on a honeycombed firing tray in a Programat P700 furnace using the firing cycle (Table 4). Each specimen was fired on the glaze fire stage once.

Fabrication of composite background

Verse-Temp Composite shade A2 with 4mm ± 0.05 mm thickness and 12mm diameter was made. 4mm was selected to mimic the buccolingual thickness of the central incisor prepared tooth (Figure 16). This composite was used as a specimen substructure (background). The composite was packed on the silicon mold (heavy putty). The composite resin discs were divided randomly into six groups using R (Version 3.1.2) for cementation. One side of the composite resin discs was coated with a single-component bonding agent (Excite, Ivoclar Vivadent) (Figure 17). The bond layer was dried with **air to remove the excess** bond layer. Composite discs were cured for 5 minutes. One side of each specimen disc was etched with 6% of hydrofluoric acid gel for 30 seconds (Ivoclar Vivadent) (Figure 18 a). Then the specimen was silanized using Monobond Plus before the application of the resin cement-luting agent (Variolink II, Ivoclar Vivadent) (Figure 18 b). All specimens and composite blocks were assembled with Variolink II (Transparent Try in Paste Variolink II, Ivoclar Vivadent) (Figure 19). Tweezers and hand pressure were used for each assembling. The cement material thickness was standardized. However, the recommended thickness was not controlled.

Testing color differences

The color differences were determined using a spectrophotometer (Crystaleye, Olympus, Tokyo, Japan). Each assembled specimen, along with the tested composite resin background, was placed in a specimen holder inside a black box. The purpose of the black box was to eliminate the influence of external light. An autopolymerizing resin (Ivolen, Ivoclar Vivadent) was used to create a custom-positioning jig (to achieve an accurate repeating measurement). The specimen was placed in the center of the display screen. The spectrophotometer was recalibrated with a calibration plate before each single test. Each reading obtained was compared to Vitapan classical dental shade A1, with 4 mm distance between the specimen surface and the tip of the spectrophotometer, and a 45^0 angle. To account for potential misreading, each specimen was imaged five times (Figures 20 - 21). The mean of the five readings was taken.

The Commission Internationale de l'Eclairage (CIE) recommends calculating color differences (ΔE) based on CIE L* a* b* color coordinates. The differences within the specimens were measured in L*, a*, and b*, and their combination was described by ΔE, as determined by the equation: $\Delta E = [(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]^{1/2}$

where L_1^*= L* of target, L_2^*= L* of reference, a_1^*= a* of target, a_2^*= a* of reference, b_1^*=b* of target, b_2^*= b* of reference.

The L* value is a measure of the lightness or darkness of the material; its coordinates range from 0 to +100. The a* value represents the measure of greenness on the negative axis and redness on the positive axis of the material color; its coordinates range from -90 to +70. The b* value represents that of yellowness on the positive side or blueness on the negative side of the material color; its coordinates range from -80 to +100.

Statistical analysis

Descriptive statistics (mean, standard deviation, median, and inter-quartile range [IQR]) were computed for each of the six experimental groups. Initially, analysis of the data via two-way ANOVA was considered; however, Levene's test indicated that the assumption of equal within-group variances was violated. Therefore, two-way ANOVA was not used. Instead, the independent-samples t-test was used for the comparison of translucencies at 1mm and 1.5mm core thicknesses. Because data from the LT5 group were not normally distributed, a non-parametric (Mann-Whitney U) test was used for the comparison of translucencies at 0.5mm core thickness. For the comparison of thicknesses at each translucency, a non-parametric (Kruskal-Wallis) test was used; a post-hoc (Mann-Whitney U) test was used with the Bonferroni correction to detect pairwise significant differences between groups. All tests of significance, aside from those in which the Bonferroni correction was used, were conducted at the $\alpha = 0.05$ level. Data analyses were conducted in IBM SPSS version 22.

Results:

Table 7 presents Lab* values of the reference group (A1 vita shade guide). Table 6 presents ΔE results for each group. For the LT15 group, 100% of ΔE values were between 1 and 3.3; for all other groups, 100% of ΔE values were above 3.3. The highest mean ΔE (9.2) was obtained for the HT5 group, and the lowest mean ΔE (2.6) was obtained for the LT15 group. For each translucency (HT and LT), 0.5 mm core thickness showed the highest ΔE, followed by the 1 mm core thickness, followed by the 1.5 mm core thickness. For each core thickness, the HT group showed higher ΔE than the LT group. The two independent-samples t-tests revealed a significant difference between the two translucencies ($p < 0.001$) at the 1mm core & 0.5 mm veneer group and the 1.5mm core group (Table 6). The Mann-Whitney U test revealed a significant difference between the translucencies ($p < 0.001$) at the 0.5mm core & 1mm veneer group (Table 6).

The Kruskal-Wallis test comparing the three thicknesses was significant ($p < 0.001$) at HT; all post-hoc tests were significant ($p \leq 0.004$). Similarly, at LT the Kruskal-Wallis test comparing the three thicknesses was significant ($p < 0.001$), and all post-hoc tests were significant ($p < 0.001$) (Table 6).

Table 7 shows descriptive statistics of Lab* values. For L*, LT values were higher than HT. LT15's mean was the closest to the reference group; HT5's mean was the furthest from the reference group. For a*, HT means were closer to the reference group than LT means, with HT5 and HT10 being the closest. LT10's mean was the furthest from the reference group. For b*, HT15's mean was the closest to the reference group; LT5's mean was the furthest. The means of the 1.5mm without veneer groups were closest to the reference, followed by the 1mm core and 0.5mm veneer groups, followed by the 0.5mm core and 1mm veneer groups. For each thickness, the HT mean was closer to the reference than the LT mean.

Discussion:

From our understanding of color theory, the identification of statistically significant differences is not enough when color differences are compared. Clinical relevance should be addressed by looking to the differences that could be detected by the human eyes. [108] Color-matching evaluation by human observers is subjective, which leads to variations in evaluation color differences and shade matching. [28] Vichi et al.[111] reported that ΔE values of less than 1 unit were not detectable to the human eye, while $1 < \Delta E < 3.3$ were considered detectable by skilled clinicians, but clinically acceptable; ΔE values greater than 3.3 were noticeable to untrained observers and were considered unacceptable. Ruyter et al.[108] estimated color difference acceptability among sample pairs of dental composite resin and found that 50% of observers considered that the ΔE of approximately 3.3 units was unacceptable.[108]

The unique property of lithium disilicate is the translucency. However, translucency is not always desirable; it depends on the remaining substructure tooth color or core build up materials. Moreover, translucency of enamel varies substantially with gender, age, and tooth color. Therefore, providers should be familiar with the level of translucencies and opacities created by each kind of ingot gives. Moreover, the desired strength of the material should be considered. A decision will have to be made between more translucency and the strength of the material as it has been shown in the literature that all ceramic material with high strength are more opaque.

Recently, lithium disilicate have been used frequently because of its superior translucency to PFM and zirconia restorations. Ivoclar Vivadent markets ingots of varying translucencies (high and low) that can be ultimately finished utilizing one of three processing methods (staining, cut-back, or layering techniques). Due to the high translucency of IPS e.max Press HT ingots, similar to that of natural enamel, they are suitable for producing smaller restorations (e.g. inlays and veneers) finalized by the staining technique. The IPS e.max Press LT ingots, on the other hand, are more suitable for creating full coverage restorations finalized by either the staining or cut-back technique. Several studies have addressed the optical properties of lithium disilicate. However, the influence of different core-veneer thicknesses and different translucencies on the final color outcome has not been evaluated. Moreover, Al Ben Ali et al. recommended that such an evaluation be conducted.[3] Thus, the main aim of the study was to evaluate the influence of core-veneer thickness and translucency level on lithium disilicate color shade A1. Translucency (high or low) and core and veneer thickness (0.5 mm core + 1mm veneer, 1mm core + 0.5 mm veneer, and 1.5 mm monolithic thicknesses) were the two variables that were tested.

Results of this study showed that there was a significant difference among the groups tested. In particular, the color difference (ΔE) of IPS Press lithium disilicate glass ceramic shade A1 was affected by translucency level and core-veneer thickness. On average, HT5 showed the highest color differences (ΔE); the lowest mean was LT15. For each translucency, the highest mean was 0.5mm core with 1mm veneer thickness, followed by 1mm core with 0.5mm veneer, followed by 1.5 mm monolithic without veneer. For each thickness, the HT group showed higher color difference (ΔE) than the LT group. These findings were in agreement with previous studies. [8,15,55,79] Brodbelt et al. stated that the translucency is light passes through a translucent material by direct transmission. The reason behind the high color difference for HT5 was the high translucency of the IPS e.max material as well as the veneer`s translucency. Chaiyabutr et al.[55] found that many factors affect the color of lithium disilicate glass ceramic, including the ceramic thickness, as well as the finding that LT groups have a smaller difference in color when compared with HT. Al Ben Ali et al.[3] showed similar findings, as the color difference of HT groups was higher compared with LT groups at different color backgrounds. However, both of these studies were conducted using IPS e.max CAD/CAM. Moreover, they evaluated different core thicknesses without applying veneer. The best explanation for why the LT groups have lower color difference than HT groups is that the HT groups have bigger crystals compared to the LT groups, which allows more light to pass through the material and then reflect the darker substructure color. It is noted that in this study, only the LT15 group exhibited ΔE values less than 3.3, which was previously defined as a standard for acceptability. [4]

In this study, the L* value (lightness), a* value (hue), and b* value (chroma) were evaluated among tested groups to achieve a more complete understanding of color difference. The ΔL^* value was greater in the LT groups compared to the HT groups. Moreover, it was less in groups with thick veneer in both HT and LT. LT15's mean was the closest to the reference group. HT5's mean was the furthest from the reference group. The best explanation is that LT contains small crystal size, which helps to mask the dark color of the background. Thus, the color of LT is more dominant than the substructure dark color.

For a* value, HT means were closer to the reference group than LT means. The closest means to the reference group were HT5 and HT10. For b* value, HT15's mean was the closest to the reference group; LT5's mean was the furthest. The means of 1.5mm thickness without veneer for both HT and LT were the closest, followed by the means of the 1mm core thickness for both HT and LT, followed by the means of the 0.5 core thickness for both translucencies. For each thickness, HT means were closer than LT means.

Numerous efforts were made in this study for all variables to be controlled that could influence the methods' standardization and color measurements. However, limitations of the study were using composite as a background instead of a natural human enamel, and luting cement thickness was not similar to the clinic cement thickness. Furthermore, this study was conducted in the lab instead of in vivo. No aging was done to the samples. Based on the literature, aging may change the final color outcome. The Crystaleye spectrophotometer provides three reading areas (Incisal, Body, and Cervical). Because we were testing uniform discs, only the body region's reading was considered in this study.

Further research

In this study, achieving an A1 final shade was attempted, while having an A2 substructure. Results from this study may help providers reach their goal in shade matching by using the three different techniques (cut-back, layering, and staining techniques) with a different range of Lab* values.

Evaluation of the effects of different background materials and colors in combination with different ingot shades may be evaluated in future studies. Additionally, evaluating the effect of the new glaze spray material on the color of lithium disilicate glass material would be recommended, as well as evaluating the translucency level of IPS e.max Press Impulse may have clinical significance. Furthermore, for any further research, we should give consideration to the results of the Lab* values.

Conclusion:

Within the limitations of the study, the following conclusion can be made:

1. Compared with low translucency, high translucency will lead to greater difference in color for lithium disilicate glass ceramic (shade A1).
2. Increasing the veneer thickness while decreasing the core thickness will lead to greater difference in color.
3. Even with the slight color difference in substructure, LT ingots are highly recommended to be used.

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APPENDICES

Appendix A: Tables

Table 1: Press cycle for IPS HT/200g investment materials ring.

Stand-by Temperature	^{0}C/min.	Firing Temperature	min.	Stop speed
700^0 C	60^0 C	915^0 C	25.00	300 m/min

Table 2: Press cycle for IPS LT/200g investment materials ring.

Stand-by Temperature	^{0}C/min.	Firing Temperature	min.	Stop speed
700^0 C	60^0 C	917^0 C	25.00	300 m/min

Table 3: Firing *IPS e.max Press* layering technique program.

Stand-by Temperature	Time	Temp. increase ^{0}C/min.	Firing Temperature	Holding Time	Holding
400^0 C	4.00	50^0 C	750^0 C	4.00	1.00

Table 4: Firing *IPS e.max Press* glazing program.

Stand-by Temperature	Time	Temp. increase ^{0}C/min.	Firing Temperature	Holding Time	Holding
400^0 C	4.00	50^0 C	725^0 C	4.00	1.00

Table 5: Lab* values of reference group (A1 vita shade guide).

Reference group	L*	a*	b*
Vita shade guide A1	75.58	-0.07	14.83

Table 6: Descriptive statistics of ΔE values, and results of significance testing*

Tested Groups	Mean	Std. Dev.	Median	IQR	ΔE<1 %	1< ΔE<3.3 %	ΔE>3.3 %	P
HT15	5.1	0.5	5.2	0.8	0%	0%	100%	<0.001**
LT15	2.6	0.5	2.6	0.7	0%	100%	0%	
HT10	7.2	1.4	7.5	1.9	0%	0%	100%	<0.001**
LT10	4.6	0.5	4.5	0.7	0%	0%	100%	
HT5	9.2	0.6	9.1	1.1	0%	0%	100%	<0.001***
LT5	7.0	0.6	6.6	1.1	0%	0%	100%	

* Results of Kruskal-Wallis test comparing HT5, HT10, and HT15 were significant ($p<0.001$). All post-hoc Mann-Whitney U tests were significant for HT ($p\leq0.004$). Results of Kruskal-Wallis test comparing LT5, LT10, and LT15 were significant ($p<0.001$). All post-hoc Mann-Whitney U tests were significant for LT ($p<0.001$).

** Independent-samples t-test
*** Mann-Whitney U test

Table 7: Descriptive statistics of Lab* values.

Tested Groups	L*		a*		b*	
	Mean	S.D	Mean	S.D	Mean	S.D
HT15	70.5	0.49	0.4	0.28	14.4	0.46
LT15	75.6	1.01	-0.95	0.81	13.17	1.23
HT10	69.0	1.5	0.2	0.18	12.5	0.24
LT10	72.9	0.45	-1.1	0.20	11.3	0.56
HT5	67.5	0.75	0.2	0.11	10.5	0.41
LT5	71.3	1.22	-0.7	0.23	9.5	0.33

Appendix B: Figures

Figure 1: 123D design software

Figure 2: Exocad software

Figure 3: Tizian Cut 5 Milling Machine.

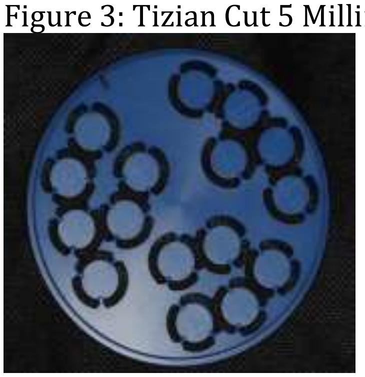
Figure 4: Milled wax block


Figure 5: Plastic ring base with discs spurred

Figure 6: Ring investment stage

Figure 7: Invested ring

Figure 8: Pressing furnace

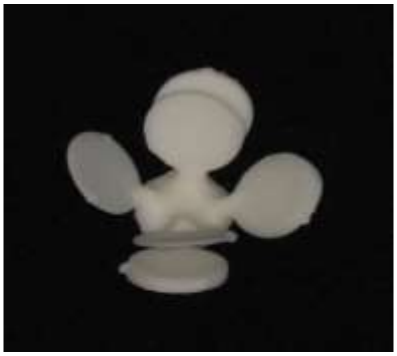

Figure 9: Discs after divest

Figure 10: Discs Measurements

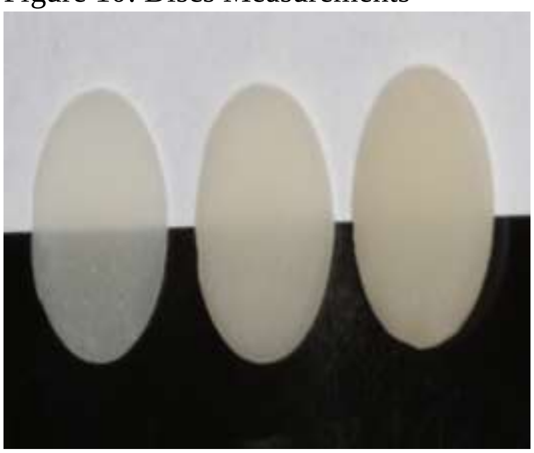

Figure 11: HT discs with three different thicknesses.

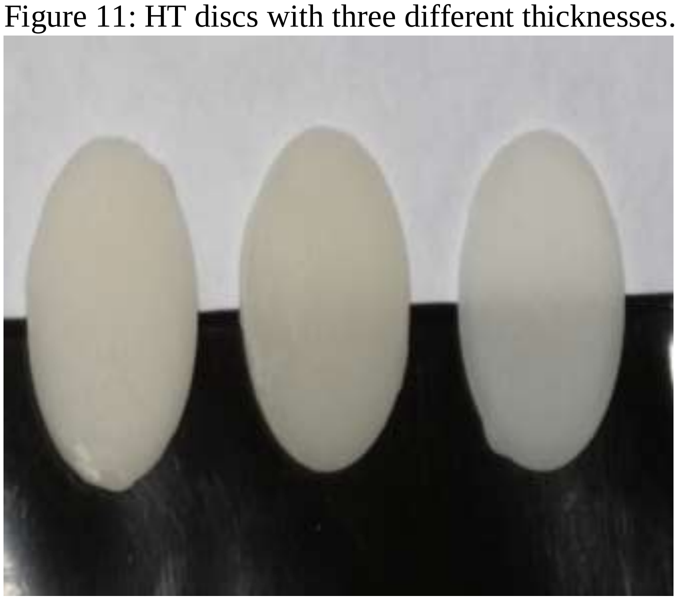

Figure 12: LT discs with three different thicknesses.


Figure 13: Applying veneer materials IT1

Figure 14: Ceramic Firing Furnace

Figure 15: Silver bar after ceramic furnace calibration

Figure 16: Versa-Temp composite material

Figure 17: Coating the composite disc with a single-component bonding agent (Excite, Ivoclar Vivadent)

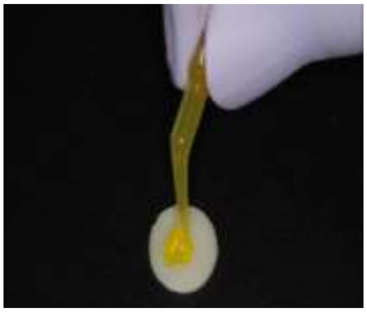

Figure 18-a: Etching one side of each specimen with 6% hydrofluoric acid gel.

Figure 18-b: Applying Monobond agent.

Figure 19: Variolink II, Ivoclar Vivadent

Figure 20: Five images for each specimen

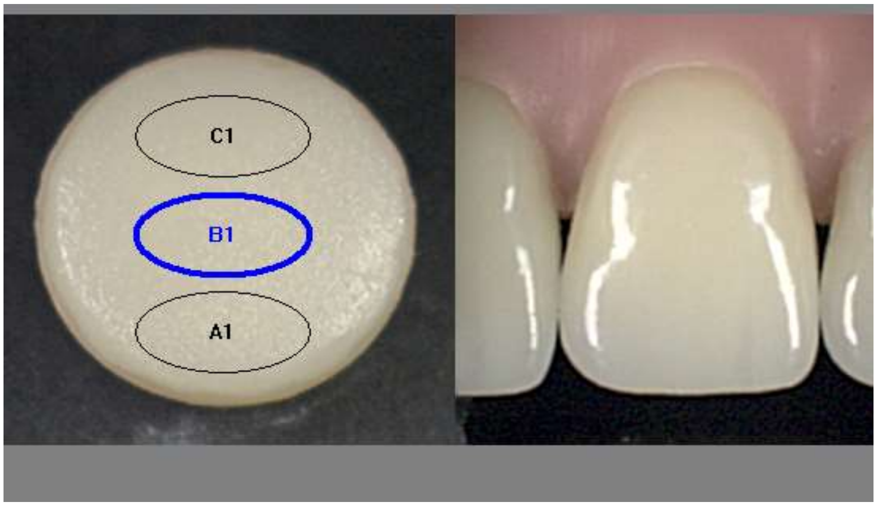

Figure 21: 2mm in diameter positioned over the middle area of the specimen.

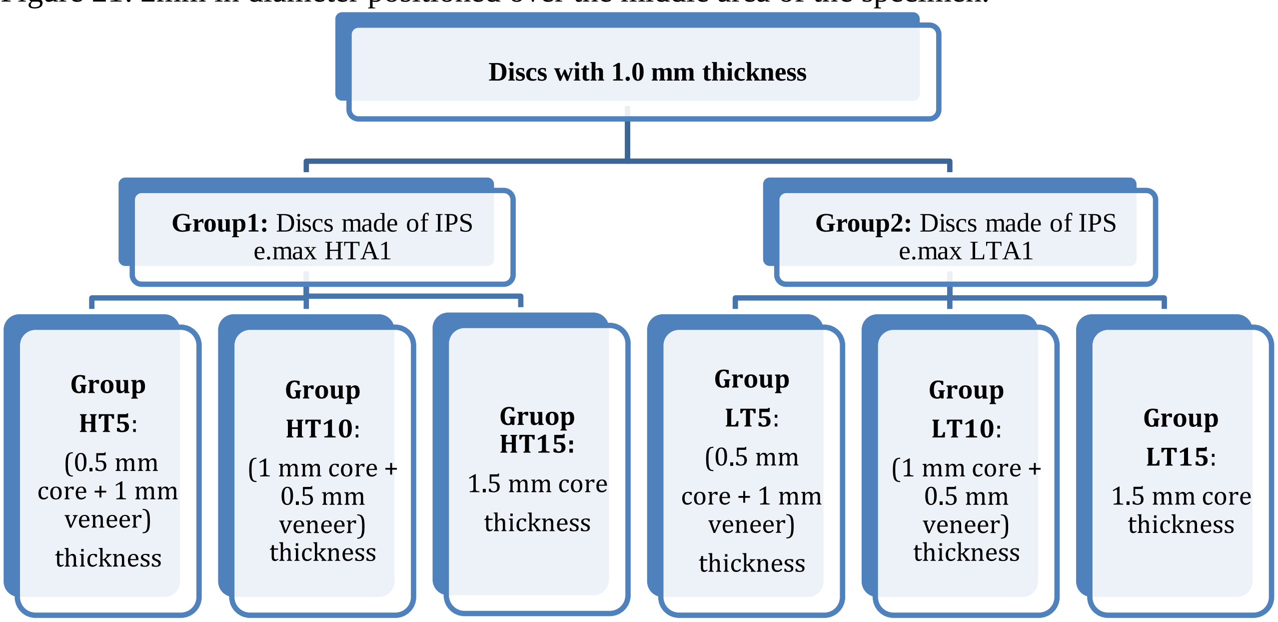

Figure 22: Experimental groups design.