Systematic Evaluation of Fluorescence in CAD/CAM Ceramic Materials

Systematic Evaluation of Fluorescence in CAD/CAM Ceramic Materials

A Thesis Presented by

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Copyright Statement Form

Dedication

This thesis is dedicated to my family and friends, who have always supported me in all aspects of life, and are the main reason I never gave up.

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I would like to thank a few people for their contributions to my career and the completion of this thesis:

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Abstract

PURPOSE: While measurements of color and translucency have been well established in dentistry, fluorescence measurements have been mostly subjective. By utilizing a microplate reader to quantify fluorescence intensity of restorative materials and natural teeth, this study can provide a method for future research in fluorescence of dental materials. The purpose of this study was to establish a clinical guideline for material selection to achieve optimal esthetic results when utilizing Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) ceramic materials for a dental prosthesis.

MATERIALS & METHODS: The intensity of fluorescence in extracted natural teeth, dentin, core materials, luting cements, and CAD/CAM ceramic materials, was initially measured. A second measurement of the fluorescence intensity was done with core materials and luting cements placed underneath the CAD/CAM ceramic materials as a layered compound. Finally, glaze was applied to the CAD/CAM ceramic materials and a third measurement of fluorescence intensity obtained.

Materials used in the study:

Core Build-up	Luting Cement	CAD/CAM	Fluorescent Dyes	Fluorescent Glazes
LuxaCore Dual	RELYX Ultimate	Katana Zirconia Material HT/ML	Lava™ Plus High Translucency Zirconia Effect Shade – Fluorescence	IPS e.max Ceram Glaze Paste/Fluo
FluoroCore 2	RELYX UNICEM	IPS e.max CAD	Colour Liquid Prettau Fluoreszenz	Fluorescent Cad Spray Glaze
ParaCore	Multilink	VITA ENAMIC CAD/CAM Material		
Build-It FR	Panavia 21 ML			

Simple descriptive statistics, mean, and standard deviations were used to describe the fluorescence intensity of extracted natural teeth, dentin substructure, core build-up materials, luting cements, and different CAD/CAM ceramic restorative materials. One-way ANOVA ($\alpha = 0.05$) was used to test if there was a statistically significant difference between the fluorescence intensity of natural teeth and CAD/CAM ceramic materials, also comparing glazed materials and layered compounds.

RESULTS: There was a significant difference in the fluorescence intensity of extracted natural-teeth when compared to dentin, core materials, luting cements, and CAD/CAM ceramic materials.

The fluorescence intensity of dentin was higher than natural teeth. Only e.max BL1 (LT and HT) had similar fluorescence intensity to natural teeth. Fluorescence of ENAMIC was similar to dentin, and Katana zirconia had no fluorescence.

CONCLUSION: Fluorescent dyes and glazes improved the fluorescence intensity of CAD/CAM ceramic materials. Fluorescent core materials and luting cements can also improve the fluorescence intensity of a complex restoration to help mimic natural teeth when used properly.

Chapter I: Background and Review of Literature

I.1 CAD/CAM in Dentistry

The goal of prosthodontics has been the reconstruction of the natural dentition in order to provide proper anatomy, strength, esthetics, and function (Baratieri et al., 2006; Chu & Ahmad, 2002; Sensi et al., 2006). The drastic increase of esthetic demands from patients has encouraged the development of many restorative materials that more closely resemble natural teeth (Denry, 1996). During the past 50 years, new restorative materials have been introduced to offer a greater range of optical properties, such as color, translucency, and fluorescence (Conrad et al., 2007; Raigrodski, 2004).

The use of Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) systems was introduced in dentistry as early as the 1970's. Dr. Francois Duret pioneered the development of dental CAD/CAM. He fabricated crowns with an optical impression of the abutment tooth that was followed by a designing and milling process (Moörmann, 2006). Later in 1985, Dr. Werner Moörmann and Dr. Marco Brandestini at Zurich University, Switzerland developed the prototype computer-assisted ceramic reconstruction or the "CEREC" 1, which was an innovative approach to fabricate all-ceramic, single- or dual-surface inlays using VITA-BLOCS MARK II (Vident) restorations chair-side in the dental office and to deliver the restoration to the patient on the same day (Mantri & Bhasin, 2010).

Other developers of dental CAD/CAM innovations include Dr. Matts Andersson, who attempted to fabricate titanium copings by combining milling and spark erosion and transformed CAD/CAM technology (Andersson et al., 1996). Andersson is known for the development of the Procera system, a processing center for the fabrication of all ceramic restorations (Brenes et al., 2016).

As CAD/CAM systems have gained popularity in dentistry, the systems used in dental applications have been simplified to include 3 components: (1) a scanner that scans models to be converted into digital data, (2) a design software to aid the digital design workflow of the digital models, and (3) a milling machine that directly transforms a selected block of ceramic material into the designed restoration.

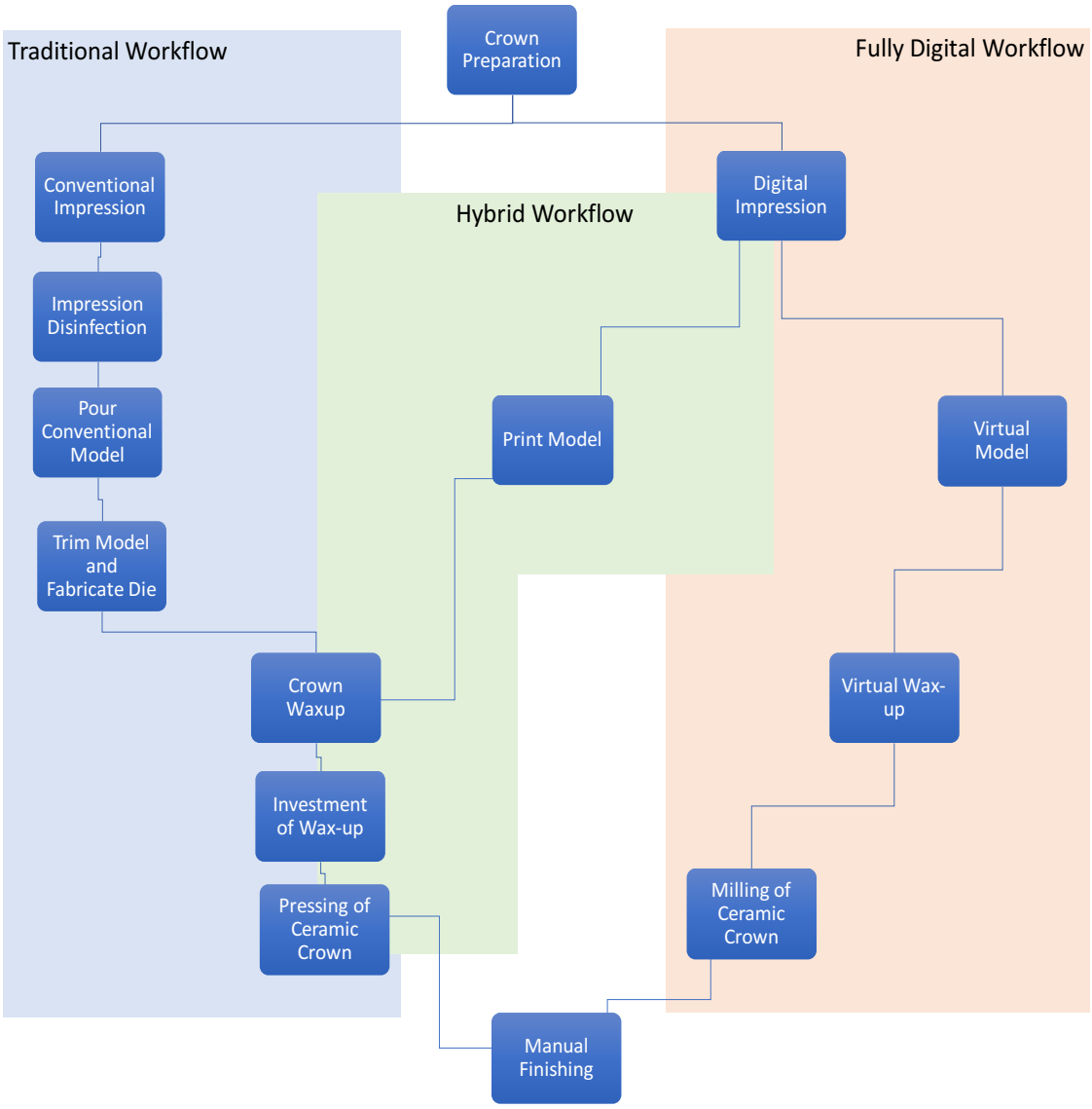

Figure 1: Comparison of steps between methods for fabrication of all-ceramic restorations.[1]

Since these advancements in the application of CAD/CAM in dentistry, other new developments have encouraged the success of the technology. For example, several modalities have been used to collect three-dimensional data of the prepared tooth or dental implant abutment using intraoral scanning, optical cameras, and contact digitization. Milling technology of crowns has improved in accuracy and efficiency by replacing conventional milling discs with specialized diamond burs.

[1] Adapted from (Brenes et al., 2016).

In addition to the application of CAD/CAM technology in the dental office for advanced chair-side dentistry, CAD/CAM systems are also utilized to meet the needs of dental laboratories. These systems are primarily used for single-unit or multiple-unit restorations. They allow for the quick and precise scanning and conversion of a stone model to a digital model and the fabrication of a larger volume and variety of restorations at a lower cost while maintaining high quality and accuracy of fit.

While it is a constant challenge for clinicians to satisfy the esthetic and treatment demands of each patient, the development of CAD/CAM-based systems has helped clinicians to improve patient satisfaction with treatment outcomes, reduce costs, lower turnaround time of treatment, and preserve the quality and esthetics of dental restorations.

I.2 Restorative Material Options

The development of CAD/CAM-based restorative systems has made possible not only prosthesis fabrication using high strength materials but also a less time-consuming process, as full-coverage restorations can be milled chair-side (Beuer et al, 2008). Moreover, improvements in restorative techniques and treatment have allowed the use of these dental materials to closely match the esthetic properties of natural teeth (Sensi et al., 2006).

There are many options for restorative materials available for CAD/CAM systems that are presented in block form, easily mounted in milling machines to be milled into various single- or multi-unit restorations. The following list consists of common restorative materials used:

1. **Feldspathic porcelain blocks:**

   The first feldspathic-based ceramic material used for the fabrication of CAD/CAM restorations was Vitablock Mark I (Vident) in 1987. Feldspathic porcelain has high translucency and, unlike lithium disilicate, has only a moderate flexural strength. In 1991 a new generation, Vita Mark II (Vident) was created. The Mark II blocks were fabricated from feldspathic porcelain particles embedded in a glass matrix. As a result of its small particle size, the second generation material reduced wear on the opposing dentition and ensured a highly esthetic restoration. However, Mark II was not strong enough to sustain occlusal loading when used for posterior crowns (Moörmann, 2006).

Figure 2: Vita Mark II Block[2]

Numerous studies have been conducted to evaluate the success and survival of the feldspathic porcelain material. A longitudinal study from Posselt and Kerschbaume investigated the survival rate (remained in the patient's mouth) and restoration failure (had to be removed) in 794 patients with 2328 ceramic inlays that were fabricated chair-side by the CEREC system. A 9-year follow-up showed a 95.5% survival rate with only 35 failed restorations. Restoration failures were mainly attributed to porcelain fracture, tooth fracture, and recurrent caries (Posselt & Kerschbaum, 2003).

2. **Leucite-reinforced porcelain blocks:**

In 1998, IPS ProCAD (Ivoclar Vivadent) was introduced as a product similar to IPS Empress but with a finer particle size designed to be used with the CEREC system (Sirona Dental). In 2006, products such as IPS Empress CAD (Ivoclar Vivadent) and Paradigm C (3M ESPE) were developed to improve the physical properties of the material (Moörmann, 2006).

The IPS Empress CAD (Ivoclar Vivadent) contained 35% to 45% leucite crystals, which was more leucite particles than the original IPS ProCAD. This reinforcement of leucite particles in the glass matrix increased the flexural strength, flexural modulus, and fracture toughness of the material. Moreover, the IPS Empress CAD (Ivoclar Vivadent) provided various color shades and levels of translucency and even customization of shades through additional stains and special try-in cement colors that lead to exceptional esthetic results (Moörmann, 2006). With high esthetic acceptability, the IPS Empress demonstrated comparable survival rates in numerous studies. Survival rates range from 92% after 3.5 years (Sjögren et al., 1999) to 94% after 6 years

[2] https://www.vita-zahnfabrik.com/en/VITABLOCS-Mark-II-25030,27568.html

(Frankenberger et al., 2000) to 95.35% after 5.7 years in 144 crowns (Fradeani et al., 1997) (Charlton et al., 2008).

3. Lithium disilicate blocks:

Lithium disilicate is a composition that includes quartz, lithium dioxide, phosphor oxide, alumina, and potassium oxide. Lithium disilicate blocks are only partially sintered and relatively soft compared to fully sintered blocks; therefore, they are more desirable in the designing and milling stage of the restoration. The blocks are usually heated to 850 °C for 20 to 30 minutes to precipitate the final phase. Multiple *in vitro* studies evaluating the marginal accuracy of milled lithium disilicate demonstrate an accuracy of 56 to 63 microns.

First introduced by Ivoclar Vivadent as Empress II in 1998, lithium disilicate was initially too opaque for full-contour restorations; therefore, they required a layering porcelain to be baked over the substructure. As the material evolved, so did the esthetic qualities as it is now available in different translucencies, appropriate for all single-crown and veneer treatments (Moörmann, 2006).

In 2005, Ivoclar Vivadent introduced IPS E.max to the market, which became well-known for its flexural strength (360-400 MPa), two to three times greater than other glass ceramics. This quality gives lithium disilicate the capability to be used in posterior restorations in patients who present bruxism or have strong occlusal load and to be used in multi-unit fixed partial dentures (Moörmann, 2006). A longitudinal study by Fasbinder evaluated the clinical performance of 62 IPS E.max full coverage crowns that were fabricated chair-side. Their results showed no crown failures and no chipping after 2 years (Fasbinder et al., 2010). IPS E.max blocks in the partially crystallized state are blue colored and are transformed to the final shade in the final crystallized state after a firing process of 20 to 25 minutes. The final product has a fine grain size of approximately 1.5 μm and 70% crystal volume (Gehrt et al., 2013).

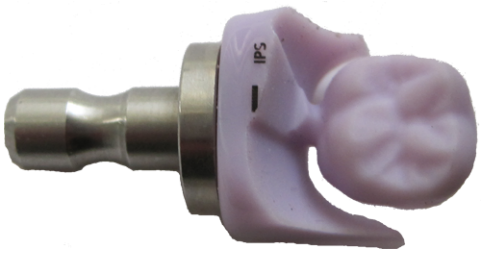

Figure 3: Milled crown from an E.max block[3]

4. Zirconia:

Zirconia is a polymorphic composition that presents in three different forms that are temperature dependent. The form of monoclinic is at room temperature, tetragonal form is above 1,170 °C, and cubic form is beyond 2,370 °C. Zirconia possess a range of volume shrinkage of 25% to 35% when heated to a temperature between 1,470 °C and 2,010 °C and then cooled. This may affect the marginal fit, passiveness, or accuracy of the restorations. (Gupta et al., 1977*;* Piconi & Maccauro, 1999; Kosmač et al., 1999)

Zirconia can be in a fully sintered zirconium oxide form or partially sintered zirconium oxide blanks, appearing in a green-state. Both stages have advantages and disadvantages in the final restoration. Milling fully sintered zirconia reduce volumetric changes during the fabrication process; therefore, improving the marginal fit or passiveness of the restoration. However, partially sintered zirconia is easier and faster to mill, which can potentially reduce micro cracks that may normally be induced from intensive or prolonged milling processes. Micro cracks or surface defects can affect the final strength of the restoration to be delivered to the patient, leading to potential chips in the marginal areas. It is suggested that further studies should be conducted on these ideas as current research is limited. (Denry & Kelly, 2008; Guazzato et al., 2002; Brenes et al., 2016)

A widely used restoration material in dentistry, zirconia is mostly utilized in the posterior areas of teeth. In 1999, In-Ceram Zirconia (Vident) was one of the first CAD/CAM systems that used zirconia. However, many companies have incorporated zirconia as a restoration material into their design and milling process due to its superior physical properties, such as favorable esthetics, high mechanical strength, fracture

[3] http://www.ktrdental.com/ipsemax.htm

toughness, and radiopacity appearance for evaluation of margin integrity (Kosmac et al., 1999; Raigrodski et al., 2004; Brenes et al, 2016).

Current zirconia materials offered by various companies include Cercon (DENTSPLY) 2004, BruxZir (Glidewell Laboratories) 2009, IPS ZirCAD (Ivoclar Vivadent) 2011, Zenostar (Ivoclar Vivadent) 2010, and inCoris ZI (Sirona Dental) 2007.

5. **Nano-ceramic hybrid blocks:**

In 2014, a new material called Enamic (VITA), an aluminum oxide, fine feldspathic porcelain, was introduced. It combined composite for its ease of handling with porcelain for its retention of surface gloss and wear resistance. The aim of this new nanotechnology material is to infiltrate composite particles into the pores of ceramic glass. Enamic was composed of polymer materials consisting of urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEG-DMA). Although the ceramic reinforced polymer network appears to have benefits of both a ceramic and resin, clinical data is limited in long-term survival rates (Raigrodski et al., 2004; Wassermann et al., 2006; Brenes et al, 2016).

6. **Composite resin blocks:**

Paradigm MZ100 (3M ESPE) was launched in 1997 and is a highly filled ultrafine silica ceramic particle-embedded product that is free of polymerization shrinkage; however, it cannot be sintered or glazed. Composite block materials are also more prone to moisture absorption; therefore, they are unfavorably affected in the esthetic appearance. (Bindl & Mörmann, 2004; Brenes et al, 2016).

I.3 The Science of Color

I.3.1 Physical Properties and the Physiology of Color Perception

In order to create highly esthetic restorations, the clinician and the laboratory technician should understand all the optical properties of a natural tooth and restorative materials. They should be able to recreate a tooth not only by matching its shape and size, but also its texture, color and fluorescence (Sensi et al, 2006).

Color is a psychophysical response that depends on the interaction between light, object and observer. Color is not a property of the object, but rather of the light that enters and is interpreted by the eye when reflected from that object. The visible spectrum, which contains all the colors visible to the human eye, exists in the range of approximately 400nm to 700nm wavelengths. As each light source contains different absorption and scattering quantities for each wavelength, the perception of color is directly affected by the light source that illuminates the object. The spectral reflection of an object determines the composition of color of that object. The curve of spectral reflection of the object represents it graphically and allows us to measure the color numerically (O'Brien et al., 1989; Sproull, 1973; Minolta, 2007)

To facilitate the categorization, description, and communication of color, numerous color systems have been proposed and used in different settings.

A classic system, Munsell's color system (see Figure 4), first created by Professor Albert H. Munsell in 1905 and revisited in 1929, defined color dimensions as being chroma, hue, and value. Hue allows the distinction between color groups such as green, red, and blue. It corresponds to the wavelength reflected by the object. Chroma is the saturation of the color and indicates its intensity. Dull colors have low saturation and the saturation increases as the color becomes more vivid. Value corresponds to the luminosity of the color that goes from pure black to pure white. Lighter colors have higher value (luminosity), and the value decreases as colors become darker. (Minolta, 2007).

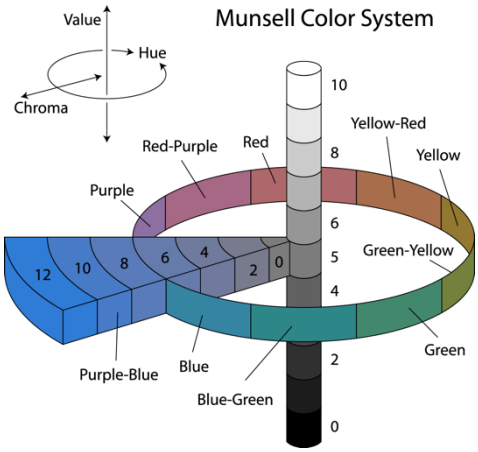

Figure 4: Munsell's Color System[4]

[4] https://commons.wikimedia.org/wiki/File:Munsell-system.svg

I.3.2 Color Spaces

In 1931, the International Commission on Illumination (CIE) defined a color space based on how the human eye perceives color (see Figure 5). The Commission defined a standard light source and a 2^0 standard observer that allowed the calculation of Tristimulus values X, Y, and Z, which represent how the cones in the human eye respond to color. A chromaticity diagram can graphically represent these values, although they are not visually uniform, and color differences are rarely based on this color system (CIE, 1978; Minolta, 2007).

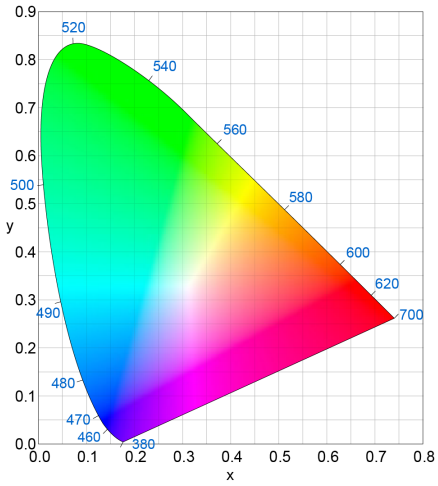

Figure 5: CIE XYZ Color System (RGB)[5]

In 1976, the CIE defined another color system, modified in 1994 and 2000, known as CIELAB, which supports the theory of color perception based in three separate receptors (red, green, and blue) and is currently one of the most popular color systems. The CIELAB color system (see Figure 6) represents a uniform space, with equal distances that correspond to the differences observed. In this tridimensional color space there are three coordinates: L*, a*, and b*. L* represents the luminosity value of an object, where L*=0 corresponds to the darkest black, and L*=100 the brightest white. The a* and b* values indicate color directions, where +a* is red, -a* green, +b* yellow, and –b*blue. When a* and b* are equal to 0, they represent the true neutral gray (CIE, 1978; Minolta, 2007).

[5] https://commons.wikimedia.org/wiki/File:CIExy1931.svg

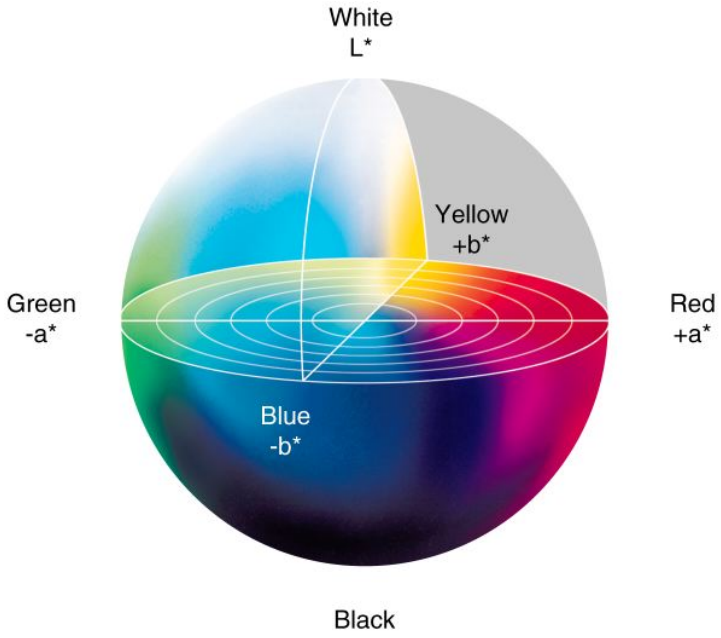

Figure 6: CIE Lab Color System[6]

I.3.3 Importance of Color and Esthetics

Clinicians face many challenges in meeting the increasing esthetic and treatment demands of patients while trying to deliver high quality restorations and treatment. These demands led to the development of a diverse selection of new metal-free ceramic systems to improve shade match and natural appearance and increase patient satisfaction.

For the tooth, color is constructed with layers. In order to improve the esthetic outcome of dental restorations, it is essential to understand the complexity of color in teeth. The color of teeth depends on its surface spectral reflectance and how the light reaching its surface is reflected, diffused, absorbed, and transmitted. The composition of color includes three commonly known color coordinates, which is hue, chroma, and lightness. In addition, translucency, fluorescence, and opalescence also play an important role in restorative material selection (Pecho et al., 2012).

The major source of color is the dentin and the enamel layer provides the translucency property. Once the light hits the tooth's surface, specular transmission and reflection will occur. Light rays are not only transmitted in different directions by the tooth's surface but are also perceived diversely by different observers. This phenomenon is the result of diffuse light transmission that occurs unevenly inside the tooth that eventually penetrates our eyes from the

[6] https://www.pinterest.com/pin/184999497165632389

tooth's surface (Arimoto et al., 2010). In enamel, hydroxyapatite crystals are responsible for this dispersion, while in dentin it is attributed mainly to the dental tubules. Enamel thickness, form, surface texture, dentin color, and light source are all aspects that can make color perception in teeth even more difficult (Ten Bosch & Coops, 1995; Van de Burgt et al., 1990; Volpato et al., 2010).

As previously mentioned, dentin is very rich in hue and chroma, while the enamel layer is highly transparent. Moreover, color is most intense in the apical regions of teeth. It is essential for the clinician and dental technician to understand these concepts to manipulate layering techniques in fabrication of restorations to improve shade matching and to mimic complex natural anatomic details and optical properties of teeth to produce life-like, highly esthetic effects. This result requires the delicate blend of shade and opacities of restorative materials into one restoration to create harmony with the adjacent natural teeth. (Gamborena & Blatz, 2011).

I.3.4 Color Measurement in Dentistry

There have been many color measuring devices available, such as dental colorimeters and spectrophotometers; however, it has only been in the last decade that dentistry has used a scientific approach to communicate tooth color. CIELAB ΔE, a magnitude of perceptual threshold, has also been implemented in color research and clinical dentistry. It has been reported that ΔE threshold for acceptable ceramic restoration in the anterior area is 2.6 units (Da Silva et al., 2008). An excellent esthetic ceramic restoration revealed an average color difference ΔE 1.5 units (Ishikawa-Nagai et al., 2009). Thus, clinical guidelines based on color science have been established by many color researchers. However, there is little known about fluorescence for natural teeth and restorative materials.

I.3.5 Translucency

Translucency can be described as "a state between complete opacity and transparency" (Pecho et al., 2012). In dental ceramic systems, translucency is dependent on the thickness, scattering, absorption coefficient, grain size, and pigmentation of the material. Furthermore, characterization of translucency includes translucency parameter, which is "defined as the color difference of material of a given thickness over a white and black backgrounds, and corresponds directly to common visual assessments" (Pecho et al., 2012). For example, a translucency parameter of zero corresponds to a completely opaque material and as translucency parameter

increases in value, translucency of the material increases. Therefore, translucency parameter is directly related to the common visual assessments of translucency and can be used to determine masking ability. As thickness of the restorative material is reduced, the translucency parameter increases.

Teeth are characterized by varying degrees of translucency that can be illustrated as a gradient between transparent and opaque. When translucency is increased (translating to lower value), light can pass the surface of the teeth or restoration and is scattered internally; therefore, less light returns to the human eye. There are different degrees of translucency in enamel and dentin, and it even varies among the different regions on the tooth. For example, the incisal third of a natural tooth features the highest degree of translucency.

It is important to understand the different translucencies of the various restorative materials available in order to fabricate the most life-like restorations. For example, Heffernan concluded that zirconia ceramics displayed higher translucency when compared to standard ceramic-metal mix systems (Heffernan et al., 2002). This higher translucency was due to lack of metallic color and transmission of zirconia structures. Even so, the translucency of zirconia ceramics was still lower than that of alumina and feldspathic porcelain options. A study by Pecho, investigating the color and translucency of zirconia ceramics and dentin, showed no statistical differences in translucency between human dentin and zirconia ceramics, suggesting a possible satisfactory esthetic replacement of dentin with zirconia ceramics (Pecho et al., 2012).

One study looked at the translucency of dental ceramics with different thicknesses. They compared 6 different types of lithium disilicate glass ceramics, 2 leucite-free glass ceramics, and 5 zirconia ceramics that were ground to predetermined thickness. A spectrophotometer was used to measure the translucency parameters. The results showed an increase in translucency parameters in all materials as thickness of the material decreased; however, the change was also material-dependent (Wang et al., 2013).

I.3.6 Fluorescence

Fluorescence is defined as “luminescence that occurs when energy is supplied by electromagnetic radiation, usually via ultraviolet (UV) light” (Gamborena & Blatz, 2011). This statement can be explained by the movement of an electron from a lower energy state to a higher, excited energy state during energy emission. Luminescence is the light that is released as energy

by the electron when it falls from an excited energy state back to a lower energy state. UV light is absorbed in fluorescent materials, giving the emitted light a longer wavelength that increases visibility and creates a "glow".

While color can be identified by conventional shade guide systems or numerical color measurements (Ishikawa-Nagai et al., 2009), other factors such as fluorescence should not be disregarded (Baratieri et al., 2006). Fluorescence is the capability that some objects have to absorb invisible energy from a light source, alter its wavelength, and emit visible light within 10^{-8}sec (Park et al., 2007).

The most notable example of fluorescence is when ultraviolet energy is absorbed from black lights and a visible blue light is emitted (Arrance, 1947; Sensi et al., 2006). Although fluorescence and phosphorescence are sometimes confused with each other, fluorescence will cease once the light is removed, whereas a phosphorescent object will continue to emit light even after the original light source is removed. Fluorescent agents have long been used in the textile and paper industries as brighteners due to their capability to make yellowish and orange materials look whiter.

Fluorescence is known to be greater in dentin than in enamel, due to the higher organic content of dentin. Cementum expresses similar fluorescence qualities as dentin, but it is still less fluorescent. It is interesting to note that carious enamel does not show fluorescence; therefore, it appears dark or black under UV light. Carious dentin also lacks fluorescence as well, with a similar dark or black appearance. This result appears when the organic structure of the tooth is affected by caries or by loss of vitality from pulpal necrosis (Benedict, 1928; Dickson et al., 1952; Hartles & Leaver, 1953).

With the advances of cosmetic dentistry, whiter teeth are often desirable but we must choose a material with the same properties of natural teeth. Sensi claimed that fluorescence is what *"*makes natural teeth look brighter and more vital," therefore the incorporation of this property in restorative materials is extremely important (Sensi et al., 2006). Stübel demonstrated the fluorescence of many different tissues in rabbits and was the first to note that natural teeth emit a strong blue fluorescence under the action of ultraviolet light (Stübel, 1911). Ecker claimed that natural teeth seem whiter and brighter in daylight due to their fluorescence, which gives the natural tooth a more vivid aspect. He states that for this reason prosthetic teeth should have the same fluorescence intensity as natural teeth (Ecker et al., 1985). Sant'Anna suggested that in order to

be unnoticeable, restorative materials need to match the fluorescence of surrounding natural teeth (Sant'Anna et al., 2007).

We are constantly exposed to different light sources with varying ultraviolet components like the sun, mercury-vapor lamps, black-lights, and the flashes used in photography. If the restorative material does not have the same fluorescent properties as the natural tooth, they could match in color under one type of light source, and be completely different under another, a phenomenon known as metamerism (Monsénégo et al., 1993)

A restorative material that doesn't match the fluorescence intensity of natural teeth can be a big problem for patients who have challenging esthetic demands, especially those who are frequently exposed to different light conditions (Sensi et al., 2006). For example, black lights can cause restorations with lower fluorescence intensity to appear dark (Figure 7), resulting in unappealing smiles and dissatisfied patients.

The goal of the restoring dentist is to mimic the optical properties of the surrounding natural teeth in a restoration. Restoring dentists and specialists should be knowledgeable on the optical properties of teeth and the restorative materials they use. Not only color but also fluorescence is important in order to provide highly esthetic and long-lasting restorations for their patients (Sensi et al., 2006). Greater understanding of fluorescence increases the vitality and richness of the restoration, allows better shade and natural esthetic control in fabrication of restorations, and minimizes the metameric effect between natural teeth and crowns under various light conditions.

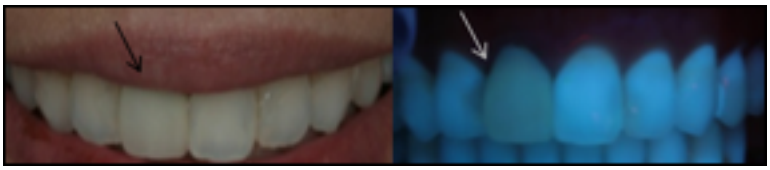

Figure 7: The ceramic crown on maxillary right central incisor has no fluorescence

Chapter II: Specific Aims and Hypothesis

The purpose of this study was to systematically and comprehensively evaluate the fluorescence intensity of Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) ceramic materials in comparison to natural teeth.

Specific Aim 1: To quantitatively measure the fluorescence intensity of extracted natural teeth, dentin substructure, different CAD/CAM ceramic materials, luting cements, and core materials.

Null Hypothesis 1:

There is no significant difference in the fluorescence intensity of extracted natural teeth and dentin substructure when compared to different CAD/CAM ceramic materials, luting cements, and core materials.

Specific Aim 2: To assess the correlation between the fluorescence intensity and the CIE L*, a* and b* of extracted natural teeth, dentin substructure and different CAD/CAM ceramic materials.

Null Hypothesis 2:

There is no statistically significant relationship between the fluorescence intensity and CIE L*, a* and b* of extracted natural teeth, dentin substructure, and different CAD/CAM ceramic materials.

Specific Aim 3: To assess the correlation between the fluorescence intensity and the translucency of different CAD/CAM ceramic materials.

Null Hypothesis 3:

There is no statistically significant relationship between the fluorescence intensity and the translucency of different CAD/CAM ceramic materials.

Specific Aims 4: To assess the effect of fluorescent dyes and glazes on the fluorescence intensity of CAD/CAM ceramic materials.

Null Hypothesis 4:

There is no significant difference in the fluorescence intensity of different CAD/CAM ceramic materials before and after the application of different fluorescent dyes and glazes.

Specific Aims 5: To assess the influence of different underlying core materials and luting cements on the fluorescence intensity of CAD/CAM ceramic.

Null Hypothesis 5:

There is no significant difference in the fluorescence intensity of CAD/CAM ceramic materials when different core materials and luting cements are used.

Chapter III: Significance and Innovation

III.1 Significance

Many studies have identified the fluorescence properties of natural teeth and different restorative materials, but typically only stated the presence or absence of fluorescence, failing to quantify the intensity of the fluorescence in each material with a reliable method.

This study is the first to provide a quantitative evaluation of the fluorescence intensity in CAD/CAM ceramic materials.

Evaluating the correlation between fluorescence, color, and translucency of CAD/CAM restorative ceramic materials will provide a better understanding of how to use these materials to mimic natural teeth.

Testing the efficacy of fluorescent dyes will provide alternative solutions for adding fluorescent properties to CAD/CAM restorations. The development of a guideline for material selection to achieve similar fluorescence intensity of natural dentition with CAD/CAM ceramic materials will improve the understanding of these materials and increase the predictability of fabricating restorations that mimic the properties of natural teeth. It will also help avoid the metameric effects caused by restorations lacking fluorescence when compared to natural teeth, which in different light settings can cause the restored tooth to appear missing. This will allow the practitioner and technician to fabricate life-like restorations and provide better esthetic results for patients.

III.2 Innovation

Experiments in this study will be the first to provide a novel approach to systematically and comprehensively evaluate CAD/CAM ceramic materials in relation to fluorescence, color, and translucency. Quantitative evaluation of fluorescence is important because in addition to stating the presence or absence of fluorescence, it can precisely determine the specific intensity of fluorescence in each specimen and layered compound.

The use of Microplate readers to quantify fluorescence intensity of restorative materials and natural teeth has not been established, therefore this study can provide a method for future research in fluorescence.

Chapter IV: Materials and Methods

IV.1 Selection of materials and preparation

IV.1.1 Natural Teeth Substrates

Ten extracted human maxillary central incisors were collected, rinsed, and had soft tissues removed. All teeth were stored in 0.1% Thymol solution. The VITA shades of the selected teeth are presented in Table 1.

Natural Tooth 1	Natural Tooth 2	Natural Tooth 3	Natural Tooth 4	Natural Tooth 5	Natural Tooth 6	Natural Tooth 7	Natural Tooth 8	Natural Tooth 9	Natural Tooth 10
B3	A1	A4	B1	A3	B4	D3	C1	C3	B2

Table 1

Each specimen was prepared as follows:

a. Each tooth was cut at the CEJ and the root surface was discarded.
b. Cutting of the specimens was done in cutting machine, Buehler Isomet 1000 at 150 rpm, with diamond disk (Figure 10).
c. These specimens were used as baseline for natural tooth fluorescence intensity.

IV.1.2 Natural Teeth for Dentin Substrates

Twenty extracted human molars were collected, rinsed, and had soft tissues removed. All teeth were stored in 0.1% Thymol solution. The VITA shades of the dentin substrates after preparation are presented in Table 2.

Dentin 1	Dentin 2	Dentin 3	Dentin 4	Dentin 5	Dentin 6	Dentin 7	Dentin 8	Dentin 9	Dentin 10
A4	A2	B3	B4	D4	C2	C3	C4	A3.5	A3
Dentin 11	Dentin 12	Dentin 13	Dentin 14	Dentin 15	Dentin 16	Dentin 17	Dentin 18	Dentin 19	Dentin 20
B2	B1	B3	B2	B1	A2	A1	A1	C1	B1

Table 2

Each specimen was prepared as follows:

a. Each tooth was cut at the CEJ and the root surface was discarded. Then, teeth were ground from the occlusal surface until the dentin layer was exposed and no enamel was left.
b. Cutting of the specimens was done in cutting machine, Buehler Isomet 1000 at 150 rpm, with diamond disk (Figure 10).
c. Grinding was done using a polishing machine (Vector Power Head, Buehler, Figure 11) with emery paper #600 and #1200.
d. These specimens were used as a baseline for natural dentin fluorescence intensity and were also used as the dentin substructure for layering purposes.

IV.1.3 Core Build-up specimens:

Four core build-up materials were used.

A. LuxaCore Dual (DMG Chemisch-Pharmazeutische Fabrik GmbH, Hamburg, Germany) – dual cure resin composite.

   Composition:

   Acrylic resin, glass powder, silica, urethane dimethacrylate (UDMA), aliphatic dimethacrylate, aromatic dimethacrylate.

B. FluoroCore 2 (Dentsply Trubyte, York, PA, USA) – dual cure resin composite.

   Composition:

   Base: Barium boron fluoro alumino silicate glass, UDMA.

   Catalyst: Barium boron fluoro alumino silicate glass, UDMA, aluminum oxide, benzoyl peroxide.

C. ParaCore (Coltene Whaledent, Altstätten, Switzerland) – dual cure resin composite.

   Composition:

   UDMA, TMPTMA, bisphenol a diglycidyl ether dimethacrylate (bis-GMA), triethylene glycol dimethacrylate (TEG/DMA), dibenzoyl peroxide, benzoyl peroxide, sodium fluoride.

D. Build-It FR (Pentron Clinical Technologies, Orange, CA, USA) – dual cure fiber-reinforced resin composite (Shade A2).

Composition:

(1-methylethylidene)bis[4,1-phenyleneoxy(2-hydroxy-3,1-propanediyl)] bismethacrylate, diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide, 1,6-hexanediyl bismethacrylate, frits, chemicals.

Two glass slides, each with a thickness of 5mm, were placed over a clean glass slab. Each core build-up material was mixed with the catalyst and placed between the two glass slides. Another clean glass slab was placed over the glass slides and finger pressure was used to hold the glass slab down. Light curing (Bluephase C8, Ivoclar Vivadent, Schaan, Liechtenstein*)* was applied to each core build-up material according to manufacturers' recommendations (Figure 8). Cured samples were then removed from the glass surface and trimmed to a square shape with a diameter of 10mm. They were kept in a clean black container to avoid surrounding light.

Five samples of each core build-up material were produced.

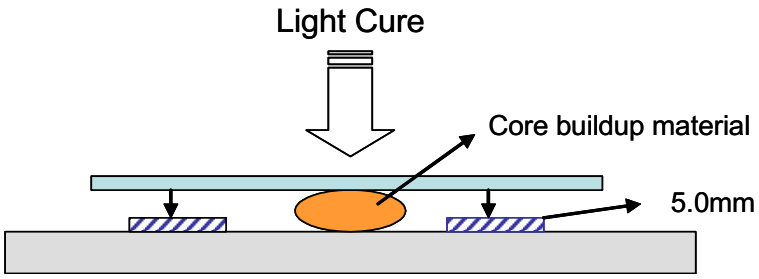

Figure 8: Core build-up acquisition

IV.1.4 Luting Cement Specimens

Four luting cements commonly used in dentistry were tested.

A. RELYX Ultimate (3M, St. Paul, MN, USA) – dual-cure adhesive resin cement (Shade B0.5).

Composition:

Base: Silane treated glass powder, 2-propenoic acid, 2-methyl-, 1,1′-[1-(hydroxymethyl)-1,2-ethanediyl] ester, reaction products with 2-hydroxy-1,3-propanediyl dimethacrylate and phosphorus oxide, triethylene glycol

dimethacrylate (TEGDMA), silane treated silica, oxide glass chemicals, sodium persulfate, tert-butyl peroxy-3,5,5-trimethylhexanoate, copper (II) acetate monohydrate.

Catalyst: Silane treated glass powder, substituted dimethacrylate, 1,12-dodecane dimethycrylate, silane treated silica, 1-benzyl-5-phenyl-barbic-acid, calcium salt, sodium p-toluenesulfinate, 2-propenoic acid, 2-methyl-, [(3methoxypropyl)imino]di-2,1-ethanediyl ester, calcium hydroxide, titanium dioxide.

B. RELYX UNICEM (3M, St. Paul, MN, USA) – self-adhesive resin cement (Shade Universal A2).

Composition:

Powder: glass fillers, silica, calcium hydroxide, self-curing initiators

Liquid: methacrylated phosphoric esters, dimethacrylates, acetate, stabilizers, self-curing initiators, light curing initiators.

C. Multilink (Ivoclar Vivadent AG, Schaan, Liechtenstein) – dual-cure resin cement (Shade White).

Composition:

Base: 2-hydroxyethyl methacrylate (HEMA), dimethacrylates, barium glass fillers, ytterbium trifluoride, silicon dioxide fillers, catalysts and stabilizers, pigments, t-amine.

Catalyst: 2-hydroxyethyl methacrylate (HEMA), dimethacrylates, barium glass fillers, ytterbium trifluoride, silicon dioxide fillers, catalysts and stabilizers, pigments, dibenzoyl peroxide.

D. Panavia 21 ML (Kuraray Noritake Dental Inc., Okayama, Japan) self-adhesive resin cement (Shade TC – Tooth color).

Composition:

Catalyst Hydrophobic aromatic dimethacrylate, hydrophobic aliphatic dimethacrylate, 10-methacryloyloxydecyl hydrogen phosphate (MDP), fillers, dibenzoyl peroxide (BPO).

Base Hydrophobic aromatic dimethacrylate, hydrophobic aliphatic dimethacrylate, hydrophilic, dimethacrylate, fillers, N,N-di(2-hydroxyethyl)p-toluidine (DEPT), sodium aromatic sulfonate.

Two pieces of clean cover glass, each with 100 microns in thickness, were placed over a clean glass slab. Each luting agent was mixed and dispensed on the glass slab between the cover glasses. Another piece of glass slab was then placed over the two cover glasses, and finger pressure was used to secure it. The luting agent was light cured according to the manufacturer's recommendation. The glass slabs were coated with plastic wrap to avoid adhesion of the luting agent to the glass. Light source was held over the middle portion of the glass slab (Figure 9). The luting cement samples were retrieved and placed in a clean black container to avoid surrounding light. Extreme care was exercised in handling to avoid breaking the samples.

Ten samples of each luting cement were produced.

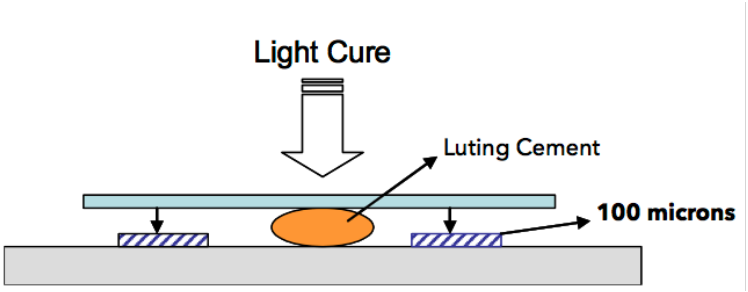

Figure 9: Luting cement acquisition

IV.1.5 CAD/CAM Specimens:

Three CAD/CAM materials were used.

A. Katana Zirconia Material HT/ML (Kuraray Noritake Dental Inc., Miyoshi, Aichi, Japan) - (Zr) - shades A light, A Dark and HT10.

   Composition: Yttria-stabilized zirconia ceramic.

B. IPS e.max CAD (Ivoclar Vivadent, Amherst, NY, USA) - (LS) - shades HT BL1, HT A1, HT A3.5, LT BL1, LT A1, LT A3.5

Composition: Lithium disilicate glass ceramic.

C. VITA ENAMIC CAD/CAM Material (VITA, Bad Säckingen, Switzerland) - (HC) - shades 0M1 HT, 2M2 HT, 0M1 T.
   Composition: acrylate polymer network infiltrated into feldspathic-based ceramic network.

Each CAD/CAM material was cut, sintered, or crystalized when adequate and polished to provide 10 x 10mm squares divided into groups of 0.5mm, 1mm, and 1.5mm.
Five samples of each specimen were provided in each thickness and shade. (Totals = Zr 45 samples, LD 90 samples, HC 45 samples).

Cutting of the specimens was done in cutting machine (Isomet 1000, Buehler, USA) at 150 rpm, with diamond disk (Figure 10).

Each Zr sample was then sintered and each LD sample crystalized according to manufacturer recommendation.

Each sample was polished using a polishing machine (Vector Power Head, Buehler, USA) with emery paper #600 and #1200. Emery paper was changed after every 10 samples were polished (Figure 11).

Each sample was verified for final thickness of 0.5mm, 1mm and 1.5mm, and 10mm diameter (0.1mm tolerance for difference) with a digital caliper (Digimatic 500, Mitutoyo, Japan).

Figure 10: Buehler Isomet 1000

Figure 11: Vector Power Head

IV.1.6 Fluorescent Dyes:

Two fluorescent dyes were tested:

A. Lava™ Plus High Translucency Zirconia Effect Shade – Fluorescence (3M ESPE, St. Paul, MN, USA).
   Composition: Glycerin, Ferric Ammonium Citrate, Water.

B. Colour Liquid Prettau Fluoreszenz (Zirkonzahn S.r.l, Gais, Italy)
   Composition: Acid base coloring liquid (not disclosed by manufacturer).

The dye was applied to green stage zirconia restorations and then dried and sintered according to manufacturer's instructions.

IV.1.7 Fluorescent Glazes:

Two fluorescent glazes were tested:

A. IPS e.max Ceram Glaze Paste/Fluo (Ivoclar Vivadent, Amherst, NY, USA)
   Composition: Glycerol, low-fusing nano-fluor-apatite glass ceramic.

B. Fluorescent Cad Spray Glaze (Nova/Indenco, Myerstown, PA, USA)
   Composition: Denatured alcohol, low fusing dental porcelain, peppermint oil.

The glazes were applied to finished zirconia and lithium disilicate restorations and baked according to manufacturer's instructions.

IV.2 Measurements of Color, Translucency and Fluorescence

IV.2.1 Measuring Instruments

A. The Filtermax F5 Multi-Mode Microplate Reader and Softmax Pro software (Molecular Devices, Sunnyvale, CA, USA) was used for the measurement of fluorescence intensity (Figure 12).

Figure 12: The Filtermax F5 Multi-Mode Microplate Reader

B. A dental spectrophotometer system, Crystaleye Spectrophotometer and Crystaleye Application Master 1.5 software (Olympus, Tokyo, Japan) was used for the measurement of color (Figure 13).

Figure 13: The Crystaleye Spectrophotometer.[7]

[7] http://www.olympus-global.com/en/news/2006b/nr061113crystale.jsp

IV.*2.2* CIELAB color coordinates L*, a*, and b* of specimens

All specimens of CAD/CAM materials, luting cements, core build-up materials, and extracted teeth had CIELab color coordinates measured using a dental spectrophotometer (Crystaleye, OLYMPUS, Tokyo, Japan). This spectrophotometer has a capture time of 0.2 sec, with 7 light emitting diodes (LEDs) used as an illumination source corresponding to the standard illuminant D65 (simulates natural daylight) with 45°/0° geometry (Figure 14).

Each specimen was be placed in a black inspection box (inspection kit, OLYMPUS, Tokyo, Japan) which shielded external light. Prior to each data acquisition, the spectrophotometer was calibrated using a calibration plate installed at the edge of its own mounting cradle. After calibration a contact cap was attached to the spectrophotometer, which assured it was positioned at a distance of 16 mm from the specimen surface. The spectral data was acquired from the captured image of each specimen.

The reflectance values in the range of 400–700 nm with 1 nm intervals for each image were transferred from the spectrophotometer to a personal computer with a Crystaleye software (Crystaleye Application Master version 1.5, Olympus, Tokyo, Japan). Three different evaluation areas (1.0 x 1.0 mm) in each specimen were identified on the captured image, and color was analyzed using CIELAB color coordinates for each sample. The average readings of CIE L*, a*, and b* were recorded.

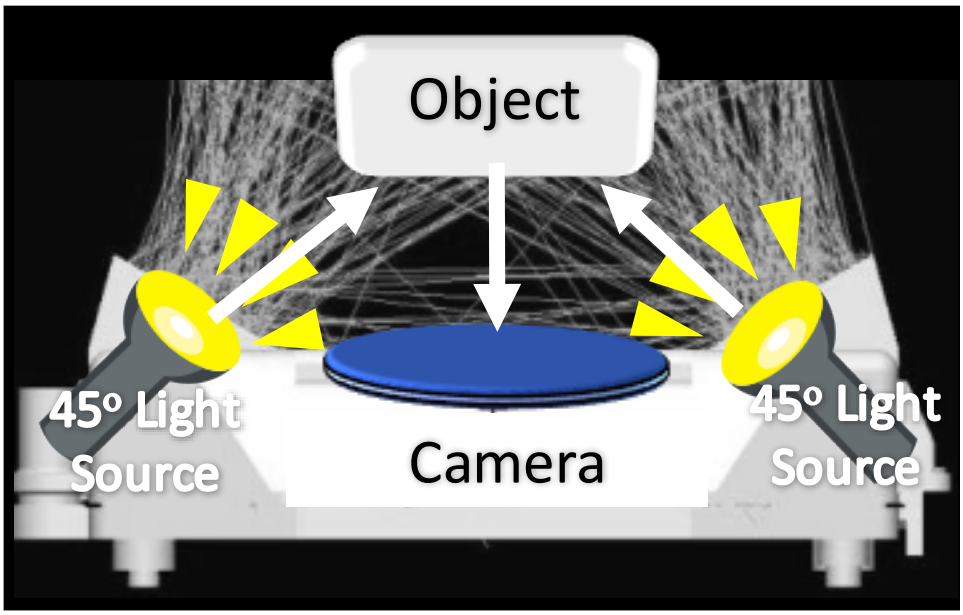

Figure 14: Dental spectrophotometer with 45° illumination and 0° observation.

IV.2.3 Translucency

A white backing (Ever-White No.9582, Evers Corporation, Osaka, Japan) was placed behind each specimen of CAD/CAM materials, luting cements, and core build-up materials inside the black inspection box. CIE L*, a*, and b* color coordinates were obtained with the same protocol previously described for the Crystaleye spectrophotometer and software. These were recorded as LW, aW and bW.

The same procedure was done using a black backing (Ever-Black No.0005, Evers Corporation, Osaka, Japan) and these were recorded as LB, aB and bB.

Translucency Parameter (TP) was calculated using the formula:

$$TP = \sqrt{(LB - LW)^2 + (aB - aW)^2 + (bB - bW)^2}$$

Contrast Ratio (CR) was calculated using the formula:

$$CR = {}^{LB}/_{LW} * 100$$

IV.2.4 Fluorescence

For fluorescence intensity, the Filtermax F5 Multi-Mode Microplate Reader and Softmax Pro software (Molecular Devices, Sunnyvale, CA, USA) were used. This microplate reader has high power LEDs that operate in the UV range, multiple options for excitation and emission filters, and a photomultiplier detection system (Figure 15). Measurement conditions were set to 360nm wavelength for excitation and 430nm wavelength for emission. These values are in accordance to previous studies reporting a peak intensity of fluorescence at these settings (Gamborena & Blatz, 2011; Lee et al., 2005; Tani et al., 2003). These microplate readers are mainly used for drug discovery, genomics, and cell-based research. Among their many capabilities, the fluorescence intensity (top read) was of interest and suitable for this study. A 12-well microplate was used, and black modeling compound placed to fill 3mm of the well. Fluorescence intensity of the modeling compound was previously measured to ensure there was no fluorescence detected. Specimens were carefully placed in the center of the well and lightly pressed for stabilization of the samples. Some wells were always left empty as a control for no fluorescence values (Figure 16).

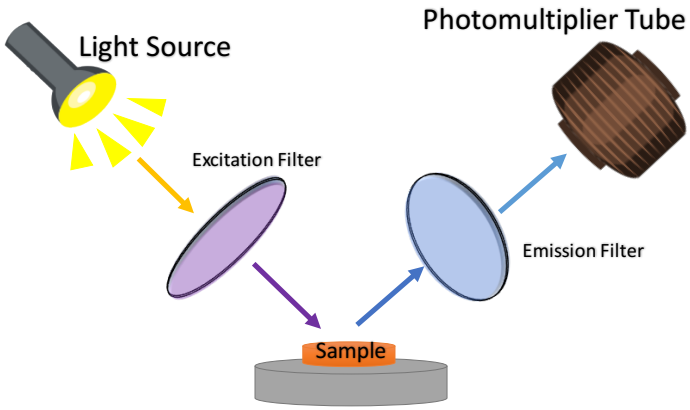

Figure 15: Schematics of a Microplate Reader

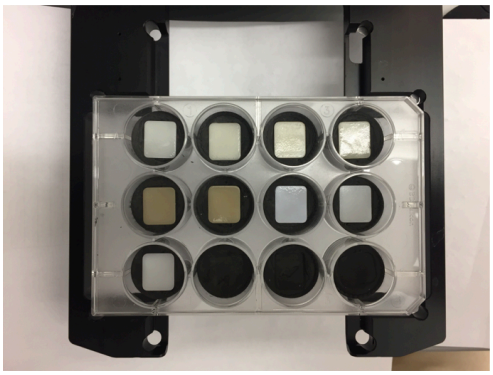

Figure 16: Microplate with samples

In single layer

Fluorescence of each specimen of the CAD/CAM materials, luting cements, core build-up materials, and extracted teeth was measured three times for each sample.

In 3-layer compound

To assess the influence of the underlying structures (core materials and luting cements) on the fluorescence of CAD/CAM ceramic materials, each of the CAD/CAM specimens was placed over a combination of luting cement and core build-up specimens or luting cement and dentin substructure. Glycerin was used to eliminate the air between all layers (fluorescence of glycerin was evaluated first to ensure no fluorescence was detected). Finally, fluorescence of the 3-layer compound, which mimics CAD/CAM ceramic restorations, was quantitatively measured (Figure 17).

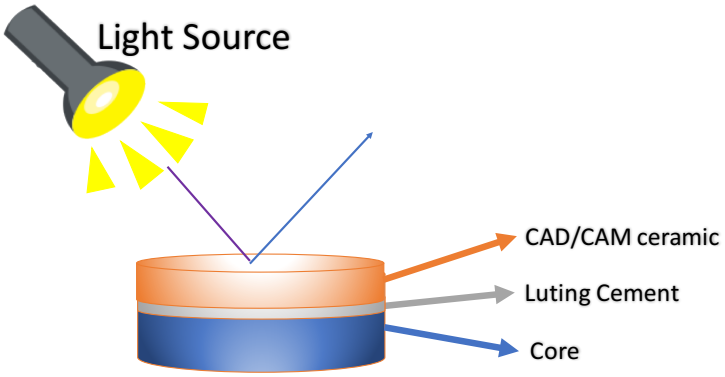

Figure 17: Three-layer compound

IV.3 Data Analysis and Statistical Analysis

A power calculation was performed to determine the sample size. The sample size was determined to provide 80% power (1-β) to recognize a significant difference of 0.5 Log10 A.U.s between groups and the standard deviation of 0.2 (preliminary data) with a 95% confidence interval ($\alpha = 0.05$), considering the change in fluorescence intensity as the primary outcome variable. A minimum of 3 samples per group would be required.

Aim 1: Simple descriptive statistics, mean, and standard deviations were used to describe the fluorescence intensity of extracted natural teeth, dentin substructure, core build-up materials, luting cements, and different CAD/CAM ceramic restorative materials. One-way ANOVA ($\alpha = 0.05$) was used to test if there was a statistically significant difference in fluorescence intensity amongst the samples. Fluorescence intensity was the dependent variable and type of material was the independent variable. Tukey's HSD post-hoc was used to verify which groups were significantly different.

Aim 2: Pearson correlation was used to assess the relationship between the fluorescence intensity of CAD/CAM ceramic materials and their L*, a*, and b* values.

Aim 3: Pearson correlation was used to assess the relationship between the fluorescence intensity of CAD/CAM ceramic materials and their translucency (TP and CR).

Aim 4: Simple descriptive statistics, mean, and standard deviations were used to describe the fluorescence intensity of CAD/CAM ceramic materials after application of fluorescent dyes or glazes. Two-way ANOVA was used to test if there was a statistically significant difference in fluorescence for each of the CAD/CAM ceramic materials before and after application of the fluorescent dye or glaze. Fluorescence intensity was the dependent variable; type of material and type of glaze were the independent variables. Tukey's HSD post-hoc was used to verify which groups were significantly different. One-way ANOVA was used to test if there was a statistically significant difference in fluorescence intensity between glazed CAD/CAM ceramic materials and extracted natural teeth.

Aim 5: Simple descriptive statistics, mean, and standard deviations were used to describe the fluorescence intensity of the 3-layer compound of materials (ceramic layer + luting cement + core material or dentin substructure). Three-way ANOVA was used to test if there was a statistically significant difference in fluorescence intensity amongst the samples. Fluorescence intensity was the dependent variable and type of material, type of luting cement, and type of core build-up material were the independent variables. Tukey's HSD post-hoc was used to verify which groups were significantly different. One-way ANOVA was used to test if there was a statistically significant difference in fluorescence intensity between the 3-layer compound of materials and extracted natural teeth.

Chapter V: Results

Means and standard deviations of the fluorescence intensity (FI), CIE L*, a*, and b* of natural teeth samples are shown in Table 3.[8]

	FI	L*	a*	b*
Natural Tooth 1	7.55 ± 0.01	71.96 ± 0.54	0.39 ± 0.68	21.74 ± 1.45
Natural Tooth 2	7.71 ± 0.01	70.28 ± 2.34	-1.28 ± 0.26	14.14 ± 2.62
Natural Tooth 3	7.48 ± 0.01	64.82 ± 0.51	2.89 ± 0.46	22.99 ± 2.61
Natural Tooth 4	7.72 ± 0.01	72.33 ± 2.11	-1.58 ± 0.33	11.62 ± 1.58
Natural Tooth 5	7.21 ± 0.01	68.83 ± 5.00	0.45 ± 1.86	20.61 ± 4.74
Natural Tooth 6	7.48 ± 0.01	68.81 ± 2.99	-0.37 ± 0.25	19.14 ± 1.51
Natural Tooth 7	7.64 ± 0.01	64.27 ± 1.05	2.71 ± 0.45	20.99 ± 5.58
Natural Tooth 8	7.61 ± 0.01	70.31 ± 4.28	-1.06 ± 0.88	17.45 ± 0.97
Natural Tooth 9	7.50 ± 0.01	63.88 ± 1.48	3.00 ± 1.12	19.09 ± 1.29
Natural Tooth 10	7.37 ± 0.01	66.75 ± 3.56	1.09 ± 1.36	23.60 ± 4.15

Table 3

Means and standard deviations of the fluorescence intensity, L*, a*, and b* of dentin samples are shown in Table 4.

	FI	L*	a*	b*
Dentin 1	8.17 ± 0.01	64.17 ± 1.52	-0.04 ± 0.27	22.62 ± 1.55
Dentin 2	8.30 ± 0.01	74.99 ± 1.22	-2.27 ± 0.54	21.90 ± 3.21
Dentin 3	8.12 ± 0.02	67.47 ± 3.99	-0.43 ± 0.71	20.51 ± 1.43
Dentin 4	8.35 ± 0.01	69.43 ± 3.00	0.52 ± 1.47	29.31 ± 2.10
Dentin 5	8.09 ± 0.03	66.91 ± 3.17	-2.05 ± 0.88	19.91 ± 3.34
Dentin 6	8.13 ± 0.01	63.44 ± 2.00	-1.51 ± 0.43	17.64 ± 1.32
Dentin 7	8.10 ± 0.01	61.95 ± 2.11	0.76 ± 0.66	21.26 ± 1.25
Dentin 8	8.11 ± 0.01	67.69 ± 1.84	-1.24 ± 0.50	21.21 ± 1.35
Dentin 9	8.19 ± 0.02	66.26 ± 0.88	2.39 ± 1.46	25.11 ± 1.35
Dentin 10	8.21 ± 0.01	74.99 ± 2.49	-2.39 ± 0.38	12.90 ± 2.68
Dentin 11	8.16 ± 0.01	74.69 ± 0.70	-3.49 ± 0.24	14.09 ± 0.51
Dentin 12	8.40 ± 0.01	71.18 ± 1.30	-3.36 ± 0.29	18.78 ± 1.72
Dentin 13	8.30 ± 0.02	71.98 ± 0.96	-2.67 ± 0.27	14.34 ± 2.35
Dentin 14	8.22 ± 0.02	73.40 ± 2.11	-3.02 ± 0.56	10.77 ± 0.75
Dentin 15	8.12 ± 0.01	74.67 ± 2.29	-2.92 ± 0.32	13.41 ± 0.89
Dentin 16	8.18 ± 0.02	80.22 ± 1.00	-2.91 ± 0.14	11.99 ± 0.96

[8] The fluorescence intensity values displayed in all tables are the Log_{10} reduction of the arbitrary units (A.U.) to facilitate interpretation and data analysis.

Dentin 17	8.06 ± 0.00	75.98 ± 1.60	-3.14 ± 0.13	14.02 ± 0.91
Dentin 18	8.22 ± 0.02	71.55 ± 2.53	-2.16 ± 0.25	10.82 ± 1.35
Dentin 19	8.24 ± 0.01	73.67 ± 2.37	-3.25 ± 0.23	11.78 ± 1.03
Dentin 20	8.34 ± 0.03	64.17 ± 1.52	-0.04 ± 0.27	22.62 ± 1.55

Table 4

Means and standard deviations of the fluorescence intensity of empty wells, black modeling compound, distilled water, and glycerin are shown in Table 5.

	FI
Empty well	5.07 ± 0.10
Modeling compound	5.07 ± 0.09
Distilled water	5.08 ± 0.08
Glycerin	5.09 ± 0.08

Table 5

Means and standard deviations of the fluorescence intensity of core material samples are shown in Table 6.

	FI
Build-it	6.90 ± 0.07
FluoroCore	8.24 ± 0.07
LuxaCore	7.81 ± 0.06
ParaCore	7.86 ± 0.04

Table 6

Means and standard deviations of the fluorescence intensity, translucency parameter (TP) and contrast ratio (CR) of luting cement samples are shown in Table 7.

	FI	**TP**	**CR**
Multilink	7.59 ± 0.02	65.18 ± 0.55	31.25 ± 0.54
Panavia21	6.87 ± 0.06	50.76 ± 0.98	44.40 ± 1.20
RelyX Ultimate	7.48 ± 0.04	60.06 ± 0.46	35.85 ± 0.94
RelyX Unicem	7.13 ± 0.08	58.69 ± 0.81	36.86 ± 0.51

Table 7

Means and standard deviations of the fluorescence intensity, CIE L*, a*, and b*, TP, and CR of Noritake Katana Zirconia samples are shown in Table 8.

	FI	L*	a*	b*	TP	CR
Noritake ML A Dark (0.5mm)	4.98 ± 0.07	64.80 ± 4.80	-2.36 ± 0.34	13.71 ± 2.31	26.36 ± 0.52	70.47 ± 0.77
Noritake ML A Dark (1.0mm)	4.88 ± 0.04	63.93 ± 4.91	-1.17 ± 0.81	17.35 ± 2.35	18.47 ± 1.03	78.63 ± 0.79
Noritake ML A Dark (1.5mm)	4.97 ± 0.15	64.08 ± 3.12	-0.60 ± 0.74	17.42 ± 2.68	12.62 ± 1.48	85.53 ± 1.51
Noritake ML A Light (0.5mm)	5.12 ± 0.10	67.22 ± 4.16	-2.51 ± 0.24	10.43 ± 2.12	25.86 ± 0.45	71.22 ± 0.60
Noritake ML A Light (1.0mm)	4.92 ± 0.11	67.12 ± 3.28	-2.29 ± 0.26	13.20 ± 2.57	18.57 ± 0.60	79.66 ± 1.03
Noritake ML A Light (1.5mm)	4.95 ± 0.12	66.35 ± 4.50	-1.88 ± 0.50	14.37 ± 2.01	12.82 ± 0.64	86.28 ± 0.90
Noritake ML HT10 (0.5mm)	5.58 ± 0.05	70.93 ± 0.61	-1.06 ± 0.15	0.02 ± 0.32	29.57 ± 0.45	66.83 ± 0.40
Noritake ML HT10 (1.0mm)	5.54 ± 0.14	72.43 ± 0.57	-1.49 ± 0.26	0.15 ± 0.24	19.77 ± 0.80	77.24 ± 1.00
Noritake ML HT10 (1.5mm)	5.56 ± 0.09	75.33 ± 0.42	-1.43 ± 0.24	0.22 ± 0.28	14.16 ± 0.54	84.09 ± 0.63

Table 8

Means and standard deviations of the fluorescence intensity, L*, a*, b*, TP, and CR of IPS e.max CAD samples are shown in Table 9.

	FI	L*	a*	b*	TP	CR
Emax HT A1 (0.5)	7.00 ± 0.02	60.19 ± 0.64	-2.33 ± 0.15	-0.04 ± 0.21	50.28 ± 0.72	42.76 ± 0.65
Emax HT A1 (1.0)	7.00 ± 0.01	63.92 ± 0.13	-1.81 ± 0.25	4.92 ± 0.28	37.69 ± 0.85	56.58 ± 0.64
Emax HT A1 (1.5)	6.98 ± 0.01	65.93 ± 0.36	-1.39 ± 0.07	7.46 ± 0.19	27.44 ± 0.67	68.51 ± 0.24
Emax HT A3.5 (0.5)	6.33 ± 0.01	54.18 ± 0.44	-1.99 ± 0.15	3.50 ± 0.53	53.06 ± 0.92	37.16 ± 0.50
Emax HT A3.5 (1.0)	6.36 ± 0.01	58.75 ± 0.44	-1.23 ± 0.20	11.17 ± 0.18	37.36 ± 0.65	55.62 ± 0.54
Emax HT A3.5 (1.5)	6.35 ± 0.02	59.72 ± 0.35	-0.29 ± 0.25	15.04 ± 0.44	27.58 ± 1.07	67.59 ± 1.08
Emax HT BL1 (0.5)	7.34 ± 0.02	63.32 ± 0.41	-2.24 ± 0.16	-4.14 ± 0.35	47.33 ± 0.92	46.77 ± 0.80
Emax HT BL1 (1.0)	7.43 ± 0.01	69.22 ± 0.37	-1.73 ± 0.18	-1.71 ± 0.31	32.92 ± 0.86	63.18 ± 0.73
Emax HT BL1 (1.5)	7.50 ± 0.04	71.90 ± 0.34	-1.46 ± 0.21	-1.23 ± 0.16	23.54 ± 0.52	73.31 ± 0.62
Emax LT A1 (0.5)	7.30 ± 0.01	67.17 ± 0.76	-2.14 ± 0.28	1.52 ± 0.97	32.09 ± 1.01	66.40 ± 1.26
Emax LT A1 (1.0)	7.21 ± 0.02	68.28 ± 0.61	-1.90 ± 0.24	7.29 ± 0.35	27.84 ± 0.87	71.78 ± 0.64
Emax LT A1 (1.5)	7.18 ± 0.01	69.35 ± 0.57	-1.69 ± 0.22	9.46 ± 0.50	18.81 ± 0.45	81.88 ± 0.46
Emax LT A3.5 (0.5)	6.42 ± 0.04	59.20 ± 0.40	-1.80 ± 0.20	8.66 ± 0.36	44.43 ± 0.98	49.67 ± 0.84
Emax LT A3.5 (1.0)	6.41 ± 0.02	61.23 ± 0.46	-0.02 ± 0.20	15.82 ± 0.51	30.90 ± 1.12	66.94 ± 0.81
Emax LT A3.5 (1.5)	6.40 ± 0.02	61.09 ± 0.29	1.33 ± 0.10	19.23 ± 0.21	21.58 ± 0.96	77.87 ± 1.05
Emax LT BL1 (0.5)	7.63 ± 0.02	76.35 ± 0.49	-1.19 ± 0.21	-6.14 ± 0.36	17.43 ± 1.16	82.15 ± 1.08
Emax LT BL1 (1.0)	7.65 ± 0.02	76.10 ± 0.39	-1.29 ± 0.14	-3.29 ± 0.35	16.73 ± 1.05	82.01 ± 0.95
Emax LT BL1 (1.5)	7.73 ± 0.01	76.45 ± 0.27	-1.25 ± 0.20	-1.71 ± 0.39	13.47 ± 1.06	85.47 ± 1.06

Table 9

Means and standard deviations of the fluorescence intensity, L*, a*, b*, TP and CR of VITA Enamic CAD/CAM samples are shown in Table 10.

	FI	L*	a*	b*	TP	CR
Enamic 0M1HT (0.5)	8.0 ± 0.01	66.12 ± 0.42	-1.17 ± 0.20	0.03 ± 0.24	42.71 ± 0.82	52.05 ± 0.66
Enamic 0M1HT (1.0)	8.16 ± 0.01	69.84 ± 0.61	-1.08 ± 0.21	2.31 ± 0.28	27.58 ± 0.83	68.52 ± 0.90
Enamic 0M1HT (1.5)	8.19 ± 0.01	72.08 ± 0.52	-1.16 ± 0.28	3.39 ± 0.23	18.35 ± 0.97	78.85 ± 1.00
Enamic 0M1T (0.5)	8.01 ± 0.02	69.40 ± 0.40	-1.10 ± 0.23	1.19 ± 0.25	37.29 ± 0.20	58.58 ± 0.24
Enamic 0M1T (1.0)	8.19 ± 0.01	73.13 ± 0.26	-1.20 ± 0.19	3.18 ± 0.31	24.71 ± 0.74	73.07 ± 0.71
Enamic 0M1T (1.5)	8.24 ± 0.01	74.71 ± 0.54	-1.18 ± 0.18	4.64 ± 0.16	16.36 ± 0.65	82.32 ± 0.59
Enamic 2M2HT (0.5)	7.85 ± 0.01	59.78 ± 0.36	-1.21 ± 0.24	4.78 ± 0.47	48.37 ± 0.52	44.30 ± 0.47
Enamic 2M2HT (1.0)	7.94 ± 0.01	64.83 ± 0.31	-0.78 ± 0.15	10.11 ± 0.24	32.79 ± 0.54	60.81 ± 0.61
Enamic 2M2HT (1.5)	8.02 ± 0.01	66.35 ± 0.22	0.09 ± 0.25	13.26 ± 0.28	24.32 ± 0.98	72.31 ± 1.17

Table 10

V.1 Specific Aim 1: To quantitatively measure the fluorescence intensity of extracted natural teeth, dentin substructure, different CAD/CAM ceramic materials, luting cements, and core materials.

Null Hypothesis 1:

There is no significant difference in the fluorescence intensity of extracted natural teeth and dentin substructure when compared to different CAD/CAM ceramic materials, luting cements, and core materials.

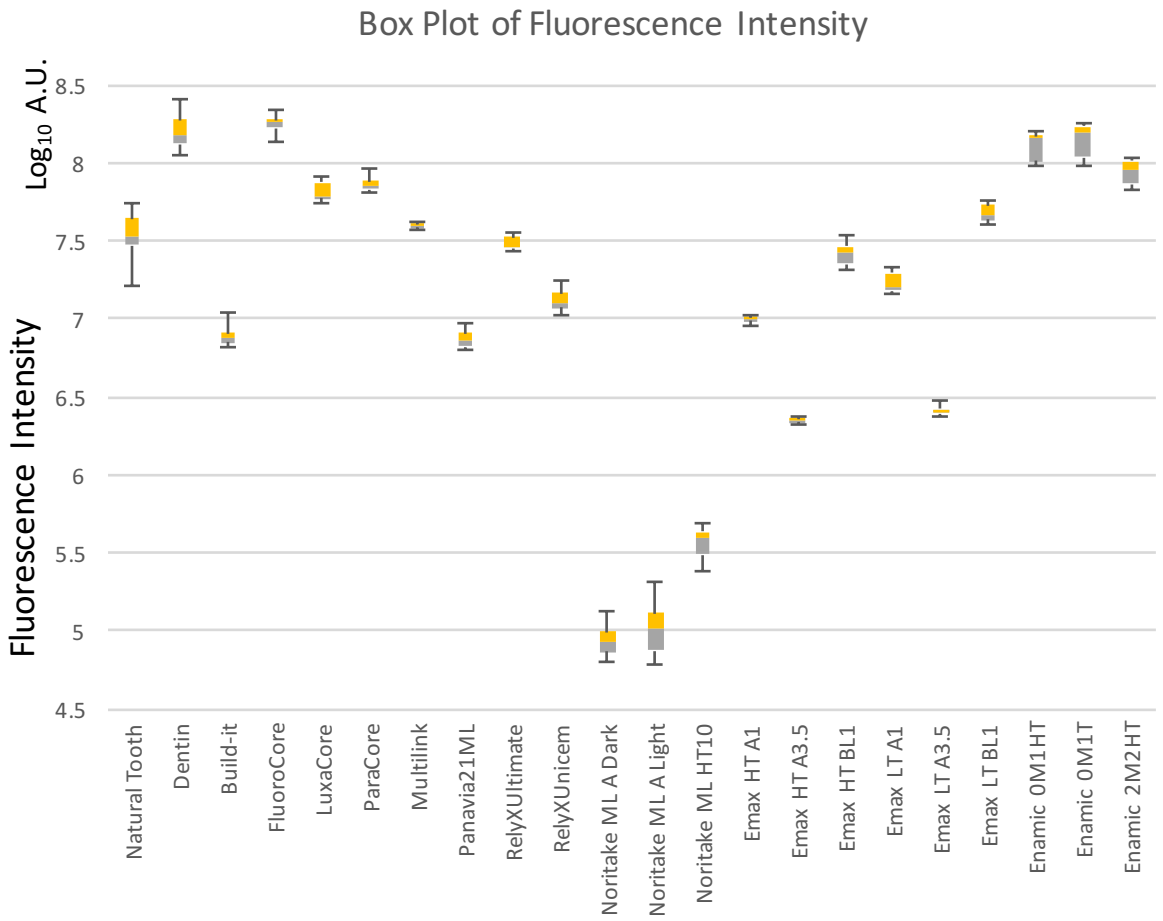

Figure 18 – Difference in fluorescence intensity among groups

Simple descriptive statistics, mean, and standard deviations were used to describe the fluorescence intensity of extracted natural teeth, dentin substructure, core build-up materials, luting cements, and different CAD/CAM ceramic restorative materials (Tables 1-7).

The data were subsequently processed and analyzed using the SPSS statistical software program (IBM SPSS Statistics for Macintosh, Version 23).

Normality tests were performed. One-way ANOVA ($\alpha = 0.05$) (Table 11) was used to test if there was a statistically significant difference in the fluorescence intensity among the samples. Fluorescence intensity was the dependent variable, and type of material was the independent variable.

The null hypothesis was rejected ($p<0.001$). There was a highly significant difference between the means of the fluorescence intensity of extracted natural teeth, dentin substructure, core build-up materials, luting cements, and different CAD/CAM ceramic restorative materials.

Tukey's HSD post-hoc (Table 12) was used to verify which groups did not have a statistically significant difference in mean of fluorescence intensity when compared to extracted natural teeth and dentin substructure.

There was no significant difference between mean fluorescence intensity of:

Natural tooth and Multilink (p=0.998)

Natural tooth and RelyXUltimate (p=1.00)

Natural tooth and e.max HT BL1 (p=0.894)

Natural tooth and e.max LT BL1 (p=0.519)

Dentin and Fluorocore (p=1.00)

Dentin and Enamic 0M1HT (p=0.461)

Dentin and Enamic 0M1T (p=0.996)

All remaining sample group combinations had a statistically significant difference in mean of fluorescence intensity.

ANOVA

Fluorescence Intensity

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	195.799	21	9.324	1453.292	.000
Within Groups	1.213	189	.006		
Total	197.012	210			

Table 11

Multiple Comparisons

Dependent Variable: Fluorescence

Tukey HSD

(I) Material	(J) Material	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Natural Tooth	Dentin	-.66864*	.05378	.000	-.9053	-.4320
	Build-it	.63288*	.05965	.000	.3706	.8952
	Fluorocore	-.70857*	.05787	.000	-.9630	-.4541
	Luxacore	-.28165*	.05532	.018	-.5265	-.0368
	Paracore	-.33147*	.05299	.004	-.5696	-.0933
	Multilink	-.06045	.04923	.998	-.2939	.1730
	Panavia21	.66515*	.05305	.000	.4286	.9017
	RelyXUltimate	.05065	.05050	1.000	-.1831	.2844
	RelyXUnicem	.40427*	.05537	.000	.1630	.6455
	Noritake ML Dark	2.58764*	.05765	.000	2.3404	2.8349
	Noritake ML Light	2.53666*	.06474	.000	2.2645	2.8088
	Noritake ML HT10	1.96910*	.05547	.000	1.7276	2.2106
	e.max HT A1	.53694*	.04904	.000	.3034	.7704
	e.max HT A3.5	1.18302*	.04919	.000	.9495	1.4165
	e.max HT BL1	.10728	.05475	.894	-.1326	.3471
	e.max LT A1	.30182*	.05250	.008	.0661	.5376
	e.max LT A3.5	1.12384*	.04954	.000	.8904	1.3573
	e.max LT BL1	-.14028	.05151	.519	-.3748	.0943
	Enamic 0M1HT	-.58152*	.05361	.000	-.8182	-.3449
	Enamic 0M1T	-.61905*	.05554	.000	-.8591	-.3790
	Enamic 2m2HT	-.40753*	.05214	.001	-.6423	-.1727
Dentin	Natural Tooth	.66864*	.05378	.000	.4320	.9053
	Build-it	1.30152*	.04099	.000	1.0978	1.5052
	Fluorocore	-.03993	.03835	1.000	-.2246	.1447
	Luxacore	.38699*	.03438	.000	.2302	.5438
	Paracore	.33718*	.03049	.000	.2061	.4683
	Multilink	.60819*	.02334	.000	.5127	.7037
	Panavia21	1.33379*	.03059	.000	1.2106	1.4570
	RelyXUltimate	.71929*	.02592	.000	.6158	.8228

	RelyXUnicem	1.07291*	.03445	.000	.9310	1.2148
	Noritake ML Dark	3.25629*	.03801	.000	3.0964	3.4162
	Noritake ML Light	3.20531*	.04809	.000	2.9929	3.4177
	Noritake ML HT10	2.63775*	.03462	.000	2.4950	2.7805
	e.max HT A1	1.20558*	.02294	.000	1.1110	1.3002
	e.max HT A3.5	1.85166*	.02327	.000	1.7563	1.9470
	e.max HT BL1	.77592*	.03346	.000	.6390	.9129
	e.max LT A1	.97047*	.02962	.000	.8517	1.0893
	e.max LT A3.5	1.79248*	.02400	.000	1.6952	1.8897
	e.max LT BL1	.52836*	.02784	.000	.4173	.6394
	Enamic 0M1HT	.08712	.03155	.461	-.0364	.2106
	Enamic 0M1T	.04959	.03473	.996	-.0871	.1863
	Enamic 2m2HT	.26111*	.02899	.000	.1477	.3745

Table 12

V.2 Specific Aim 2: To assess the correlation between the fluorescence intensity and the CIE L*, a*, and b* of extracted natural teeth, dentin substructure, and different CAD/CAM ceramic materials.

Null Hypothesis 2:

There is no statistically significant relationship between the fluorescence intensity and CIE L, a*, and b* of extracted natural teeth, dentin substructure and different CAD/CAM ceramic materials.*

Simple descriptive statistics; mean and standard deviations were used to describe the fluorescence intensity, L*, a* and b* values of extracted natural teeth, dentin substructure and different CAD/CAM ceramic restorative materials (Tables 1-7).

The data were subsequently processed and analyzed using the SPSS statistical Software program (IBM SPSS Statistics for Macintosh, Version 23).

V.2.1.CIELAB of Natural Teeth and its correlation to Fluorescence Intensity:

A Pearson product-moment correlation coefficient was computed to assess the relationship between the fluorescence intensity of extracted natural teeth and their L*, a*, and b* values (Table 13).

Correlation between Fluorescence Intensity and L*, a* and b* of Natural Teeth

		Fluorescence	L*	a*	b*
Fluorescence	Pearson Correlation	1	.279	-.327	-.666+
	Sig. (2-tailed)		.435	.357	.035
	N	10	10	10	10

Table 13

There was no statistically significant correlation between the fluorescence intensity and the L* of extracted natural teeth (p=0.435), (r=0.279). A scatterplot summarizes the results (Figure 19). Overall, there was no significant linear correlation between the fluorescence intensity and the L*.

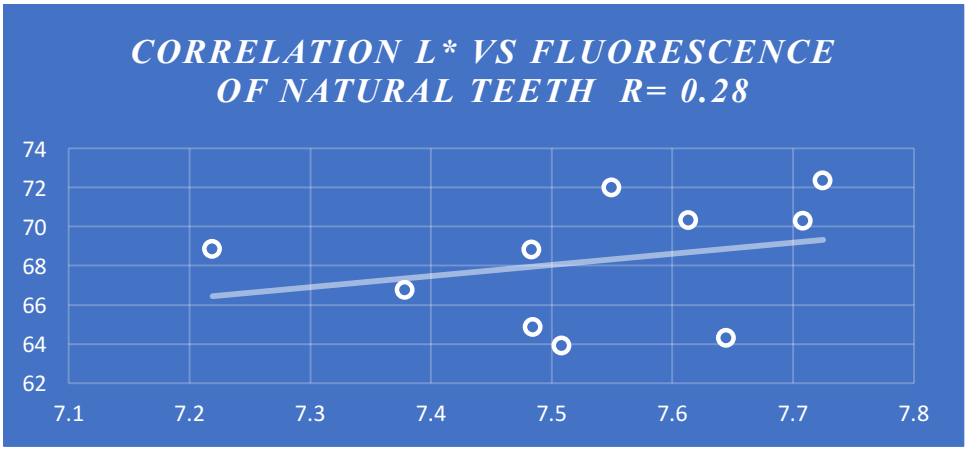

Figure 19

There was no statistically significant correlation between the fluorescence intensity and the a* of extracted natural teeth (p=0.357), (r=-0.327). A scatterplot summarizes the results (Figure 20). Overall, there was no significant linear correlation between the fluorescence intensity and the a*.

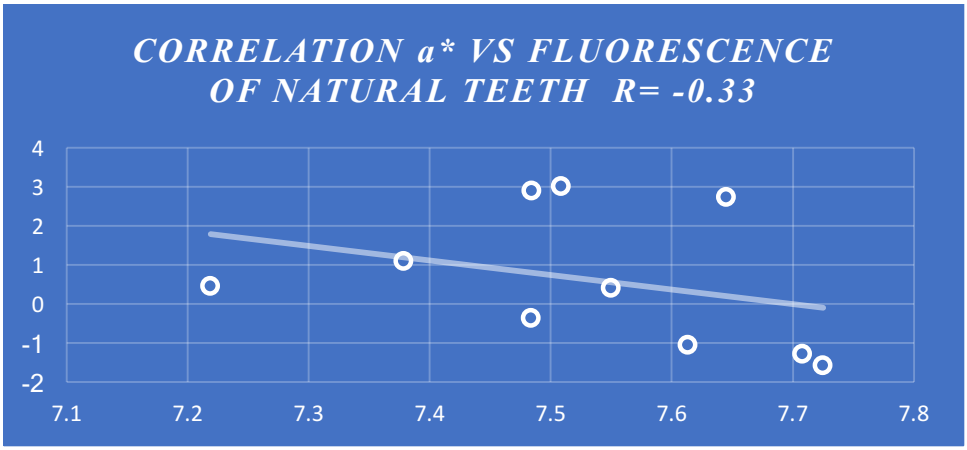

Figure 20

There was a statistically significant negative correlation between the fluorescence intensity and the b* of extracted natural teeth (p=0.035), (r=-0.666). A scatterplot summarizes the results (Figure 21). Overall, there was a moderate negative linear correlation between the fluorescence intensity and b*. Increases in the fluorescence intensity were correlated with decreases in the b*.

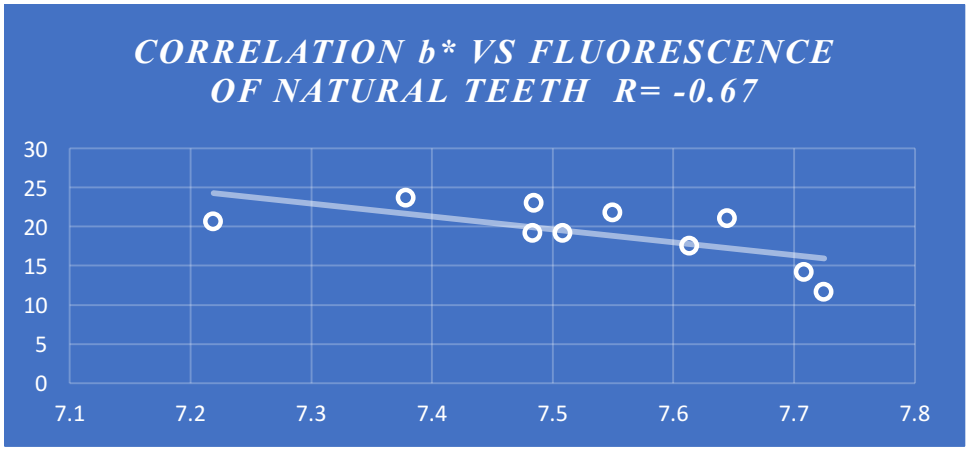

Figure 21

V.2.2. CIELAB of Dentin and its correlation to Fluorescence Intensity:

A Pearson product-moment correlation coefficient was computed to assess the relationship between the fluorescence intensity of dentin and their L*, a*, and b* values (Table 14).

Correlation between Fluorescence Intensity and L*, a*, and b* of Dentin

		Fluorescence	L*	a*	b*
Fluorescence	Pearson Correlation	1	.289	-.233	.045
	Sig. (2-tailed)		.231	.338	.855
	N	20	20	20	20

Table 14

There was no statistically significant correlation between the fluorescence intensity and the L* of dentin (p=0.231), (r=0.289). A scatterplot summarizes the results (Figure 22). Overall, there was no significant linear correlation between the fluorescence intensity and the L*.

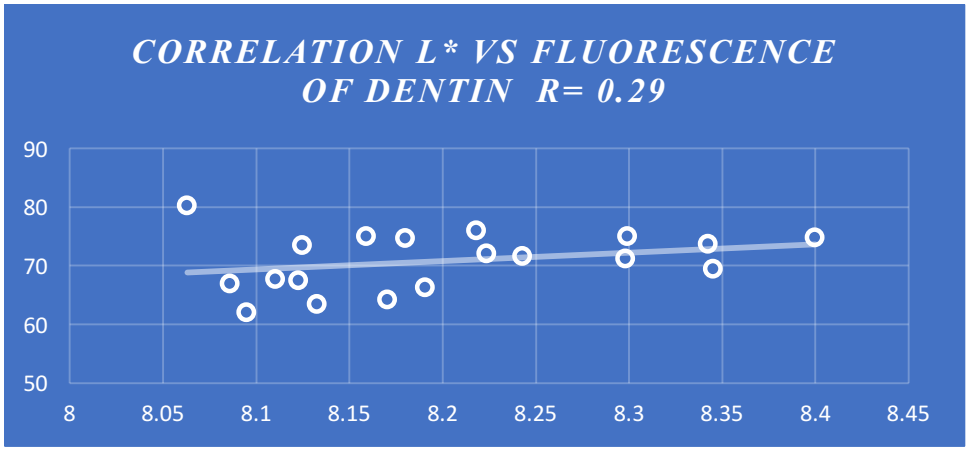

Figure 22

There was no statistically significant correlation between the fluorescence intensity and the a* of dentin (p=0.338), (r=-0.233). A scatterplot summarizes the results (Figure 23). Overall, there was no significant linear correlation between the fluorescence intensity and the a*.

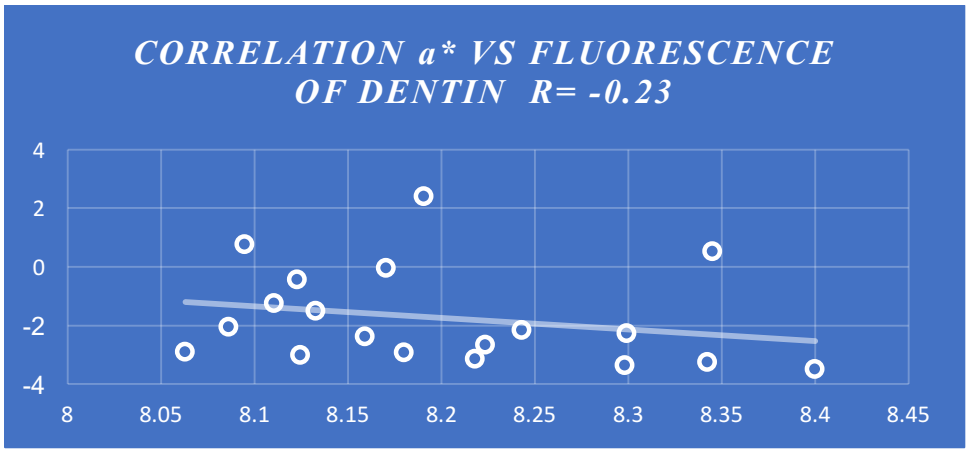

Figure 23

There was no statistically significant correlation between the fluorescence intensity and the b* of dentin (p=0.855), (r=0.045). A scatterplot summarizes the results (Figure 24). Overall, there was no significant linear correlation between the fluorescence intensity and the b*

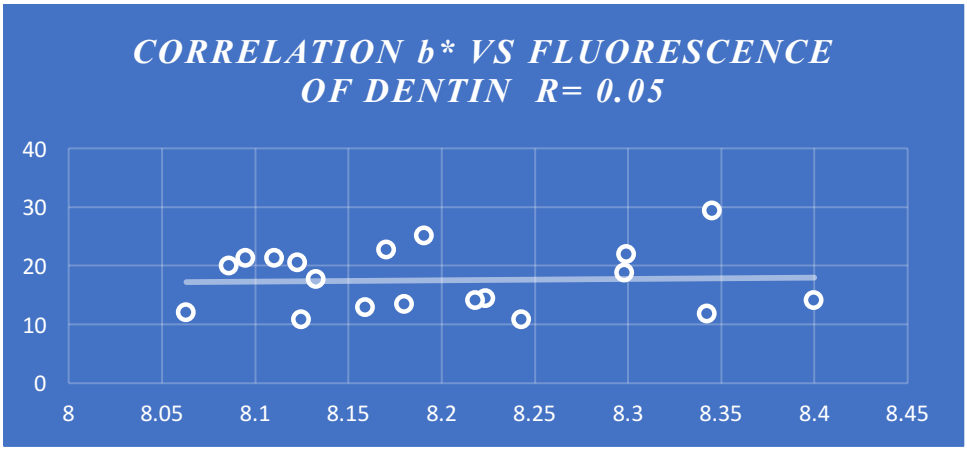

Figure 24

V.2.3. CIELAB of CAD/CAM Materials and its correlation to Fluorescence Intensity:

V.2.3.1. CIELAB of Noritake Katana Zirconia Material HT/ML and its correlation to Fluorescence Intensity

A Pearson product-moment correlation coefficient was computed to assess the relationship between the fluorescence intensity of Katana Zirconia samples and their L*, a*, and b* values (Table 15).

Correlation between Fluorescence Intensity and L*, a*, and b* of Noritake Katana Zirconia

		Fluorescence	L*	a*	b*
Fluorescence	Pearson Correlation	1	.887**	-.345	-.949**
	Sig. (2-tailed)		.000	.067	.000
	N	45	45	45	45

Table 15

There was a statistically highly significant positive correlation between the fluorescence intensity and the L* of Noritake Katana Zirconia samples ($p<0.001$), ($r=0.887$). A scatterplot summarizes the results (Figure 25). Overall, there was a strong positive linear correlation between the fluorescence intensity and L*. Increases in the fluorescence intensity were correlated with increases in the L*.

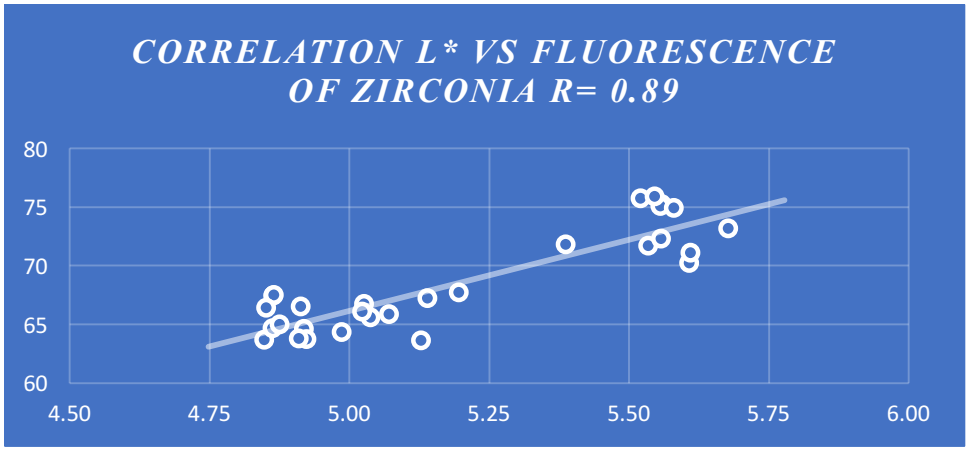

Figure 25

There was no statistically significant correlation between the fluorescence intensity and the a* of Noritake Katana Zirconia samples (p=0.067), (r=-0.345). A scatterplot summarizes the results (Figure 26). Overall, there was no significant linear correlation between the fluorescence intensity and the a*.

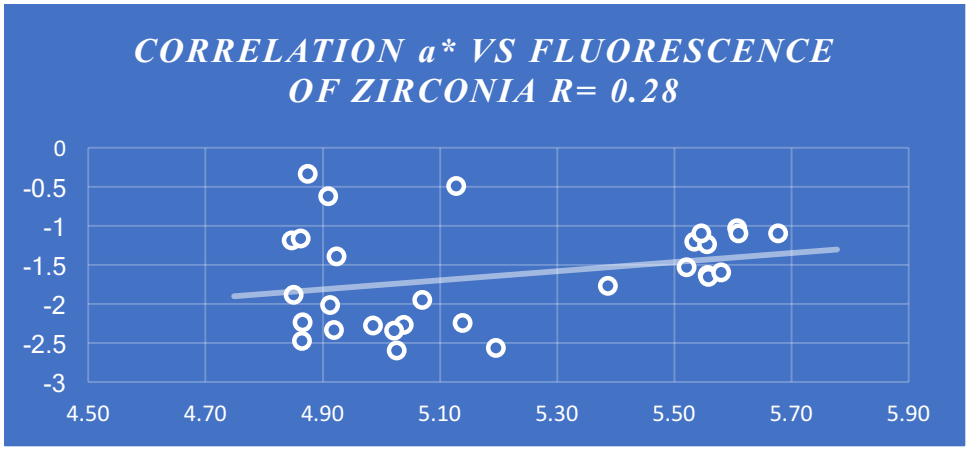

Figure 26

There was a statistically highly significant negative correlation between the fluorescence intensity and the b* of Noritake Katana Zirconia samples (p<0.001), (r=-0.949). A scatterplot summarizes the results (Figure 27). Overall, there was a very strong negative linear correlation between the fluorescence intensity and b*. Increases in the fluorescence intensity were correlated with decreases in the b*.

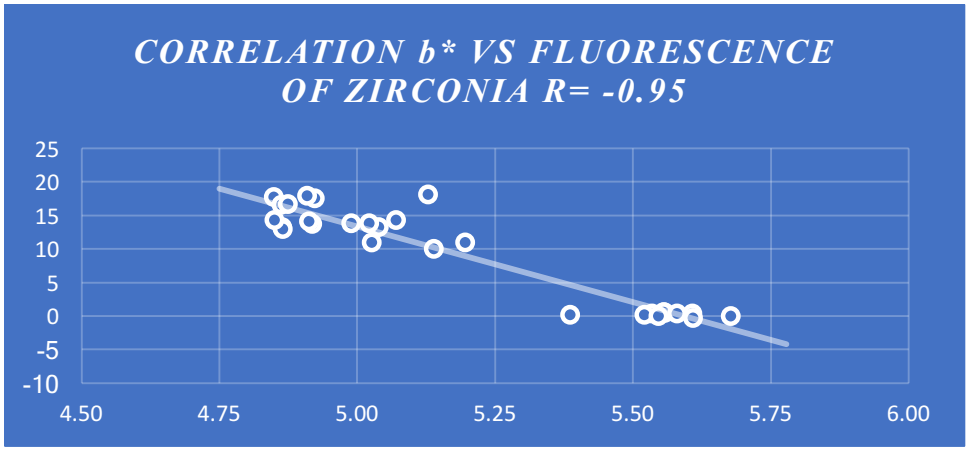

Figure 27

V.2.3.2 CIELAB of IPS e.max CAD HT and its correlation to Fluorescence Intensity

A Pearson product-moment correlation coefficient was computed to assess the relationship between the fluorescence intensity of IPS e.max CAD HT samples and their L*, a*, and b* values (Table 16).

Correlation between Fluorescence Intensity and L*, a*, and b* of IPS e.max CAD HT

		Fluorescence	L*	a*	b*
Fluorescence	Pearson Correlation	1	.876**	-.394*	-.804**
	Sig. (2-tailed)		.000	.042	.000
	N	45	45	45	45

Table 16

There was a statistically highly significant positive correlation between the fluorescence intensity and the L* of IPS e.max CAD HT samples ($p<0.001$), ($r=0.876$). A scatterplot summarizes the results (Figure 28). Overall, there was a strong positive linear correlation between the fluorescence intensity and L*. Increases in the fluorescence intensity were correlated with increases in the L*.

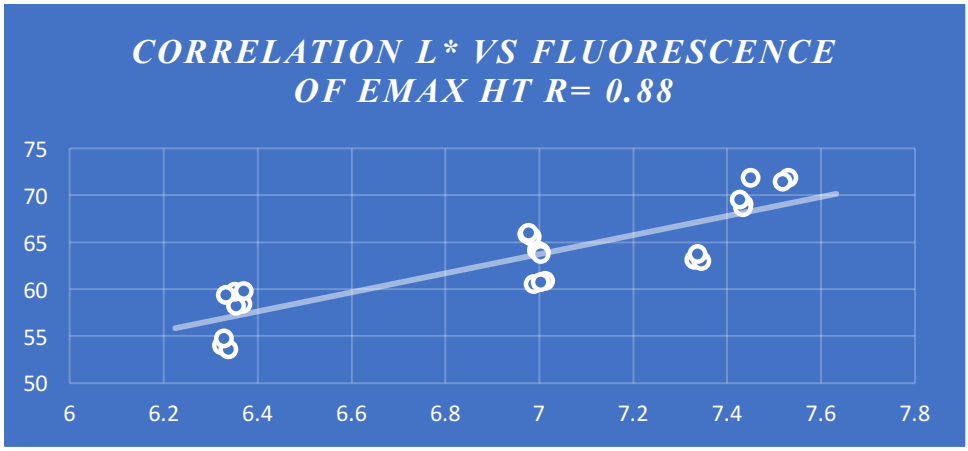

Figure 28

There was a statistically significant negative correlation between the fluorescence intensity and the a* of IPS e.max CAD HT samples (p=0.042), (r=-0.394). A scatterplot summarizes the results (Figure 29). Overall, there was a weak negative linear correlation between the fluorescence intensity and a*. Increases in the fluorescence intensity were correlated with decreases in the a*.

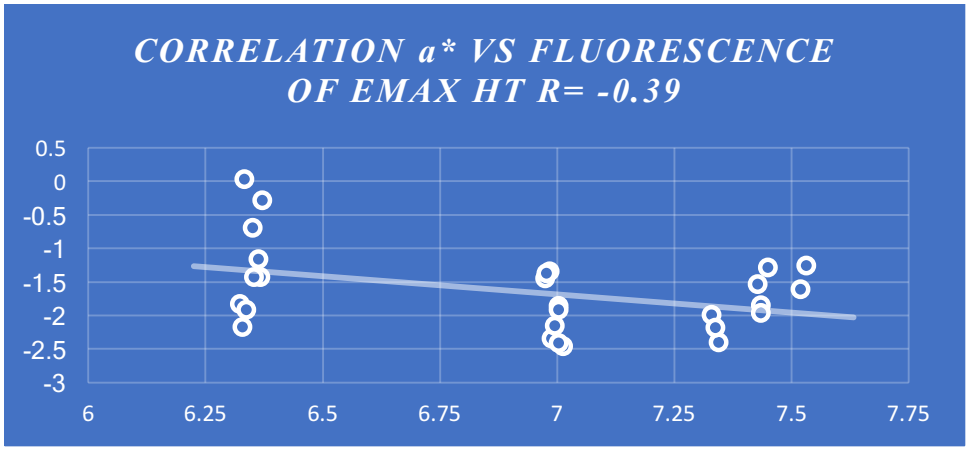

Figure 29

There was a statistically highly significant negative correlation between the fluorescence intensity and the b* of IPS e.max CAD HT samples (p<0.001), (r=-0.804). A scatterplot summarizes the results (Figure 30). Overall, there was a strong negative linear correlation between the fluorescence intensity and b*. Increases in the fluorescence intensity were correlated with decreases in the b*.

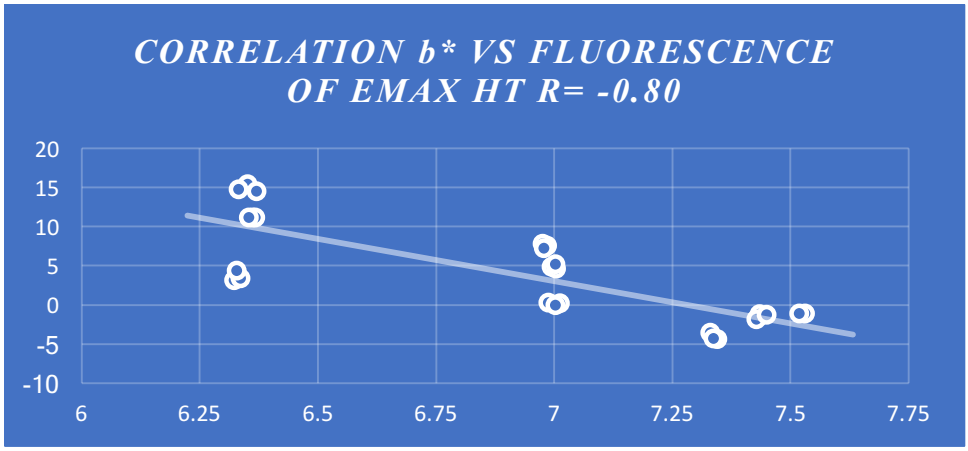

Figure 30

V.2.3.4 CIELAB of IPS e.max CAD LT and its correlation to Fluorescence Intensity

A Pearson product-moment correlation coefficient was computed to assess the relationship between the fluorescence intensity of IPS e.max CAD LT samples and their L*, a*, and b* values (Table 17).

Correlation between Fluorescence Intensity and L*, a*, and b* of IPS e.max CAD LT

		Fluorescence	L*	a*	b*
Fluorescence	Pearson Correlation	1	.970**	-.493**	-.898**
	Sig. (2-tailed)		.000	.009	.000
	N	45	45	45	45

Table 17

There was a statistically highly significant positive correlation between the fluorescence intensity and the L* of IPS e.max CAD LT samples ($p<0.001$), ($r=0.970$). A scatterplot summarizes the results (Figure 31). Overall, there was a very strong positive linear correlation between the fluorescence intensity and L*. Increases in the fluorescence intensity were correlated with increases in the L*.

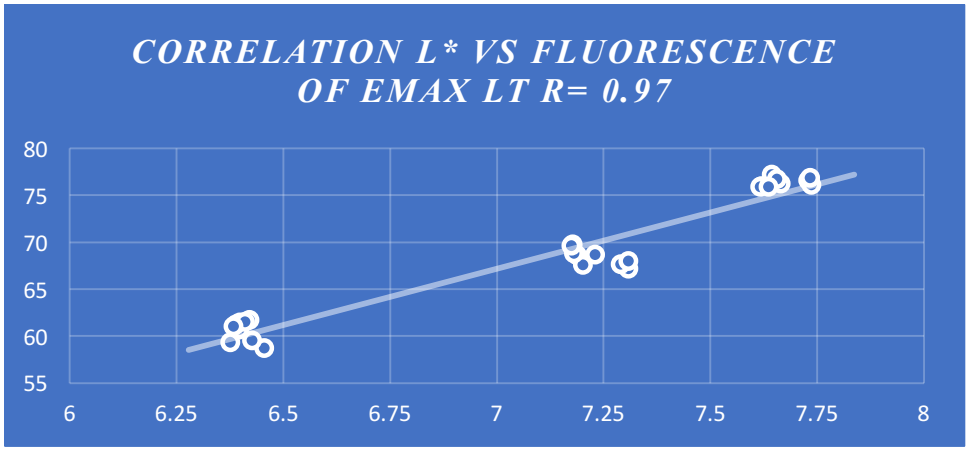

Figure 31

There was a statistically significant negative correlation between the fluorescence intensity and the a* of IPS e.max CAD HT samples (p=0.009), (r=-0.493). A scatterplot summarizes the results (Figure 32). Overall, there was a weak negative linear correlation between the fluorescence intensity and a*. Increases in the fluorescence intensity were correlated with decreases in the a*.

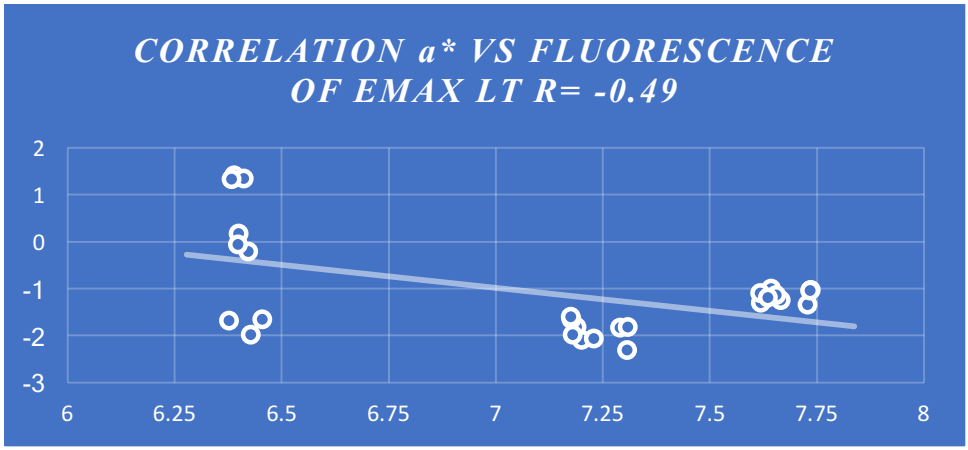

Figure 32

There was a statistically highly significant negative correlation between the fluorescence intensity and the b* of IPS e.max CAD HT samples (p<0.001), (r=-0.898). A scatterplot summarizes the results (Figure 33). Overall, there was a strong negative linear correlation between the fluorescence intensity and b*. Increases in the fluorescence intensity were correlated with decreases in the b*.

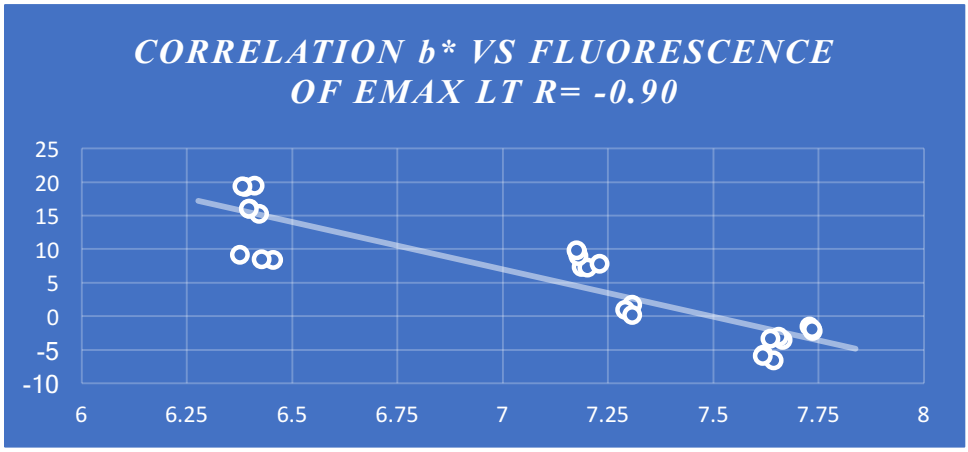

Figure 33

V.2.3.5 CIELAB of VITA ENAMIC CAD/CAM Material and its correlation to Fluorescence Intensity

A Pearson product-moment correlation coefficient was computed to assess the relationship between the fluorescence intensity of VITA Enamic CAD/CAM samples and their L*, a*, and b* values (Table 18).

Correlation between Fluorescence Intensity and L*, a* and b* of VITA Enamic CAD/CAM

		Fluorescence	L*	a*	b*
Fluorescence	Pearson Correlation	1	.957**	-.208	-.253
	Sig. (2-tailed)		.000	.171	.093
	N	45	45	45	45

Table 18

There was a statistically highly significant positive correlation between the fluorescence intensity and the L* of VITA Enamic CAD/CAM samples ($p<0.001$), ($r=0.957$). A scatterplot summarizes the results (Figure 34). Overall, there was a very strong positive linear correlation between the fluorescence intensity and L*. Increases in the fluorescence intensity were correlated with increases in the L*.

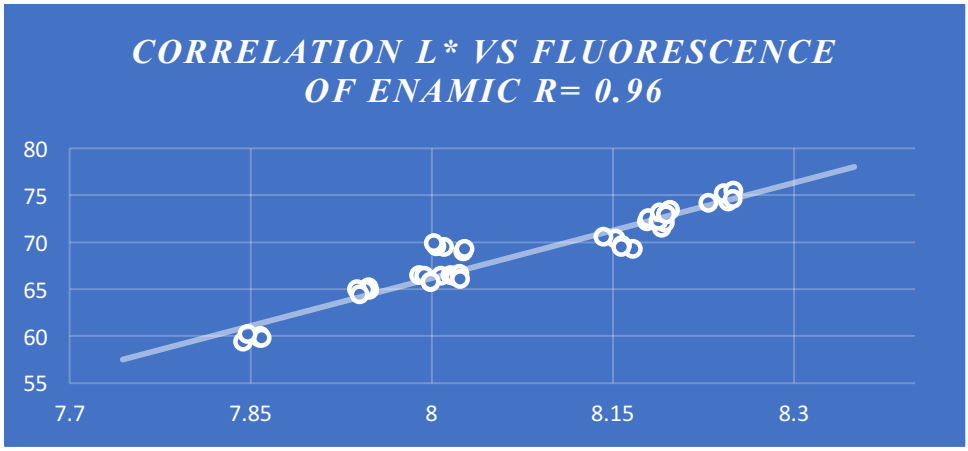

Figure 34

There was no statistically significant correlation between the fluorescence intensity and the a* of VITA Enamic CAD/CAM samples (p=0.171), (r=-0.208). A scatterplot summarizes the results (Figure 35). Overall, there was no significant linear correlation between the fluorescence intensity and the a*.

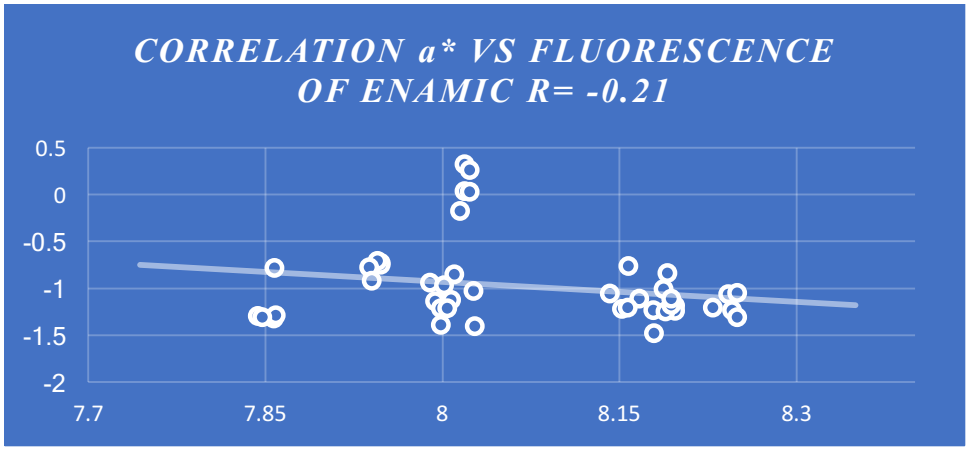

Figure 35

There was no statistically significant correlation between the fluorescence intensity and the b* of VITA Enamic CAD/CAM samples (p=0.093), (r=-0.253). A scatterplot summarizes the results (Figure 36). Overall, there was no significant linear correlation between the fluorescence intensity and the b*.

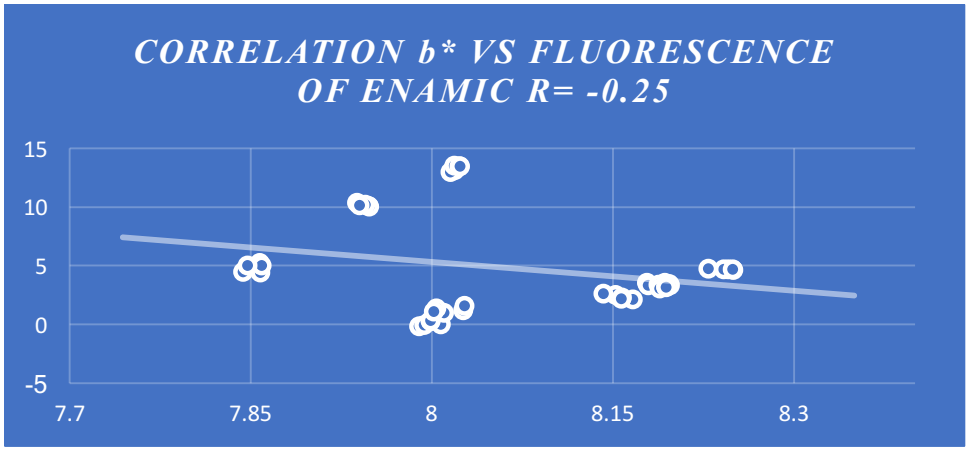
CORRELATION b* VS FLUORESCENCE OF ENAMIC R= -0.25
15
10
5
0
-5
7.7
7.85
8
8.15
8.3

Figure 36

V.3 Specific Aim 3: To assess the correlation between the fluorescence intensity and the translucency of different CAD/CAM ceramic materials.

Null Hypothesis 3:

There is no statistically significant relationship between the fluorescence intensity and the translucency of different CAD/CAM ceramic materials.

V.3.1. Translucency of CAD/CAM Materials and its correlation to Fluorescence Intensity:

V.3.1.1 Translucency of Katana Zirconia Material HT/ML and its correlation to Fluorescence Intensity

A Pearson product-moment correlation coefficient was computed to assess the relationship between the fluorescence intensity of Katana Zirconia samples with their translucency parameter (TP) and contrast ratio (CR) values (Table 19).

Correlation between Fluorescence Intensity and Translucency of Noritake Katana Zirconia

		Fluorescence	Translucency Parameter	Contrast Ratio
Fluorescence	Pearson Correlation	1	.145	-.171
	Sig. (2-tailed)		.454	.376
	N	45	45	45

Table 19

There was no statistically significant correlation between the fluorescence intensity and the TP of Noritake Katana Zirconia samples (p=0.454), (r=0.145). A scatterplot summarizes the results (Figure 37). Overall, there was no significant linear correlation between the fluorescence intensity and TP.

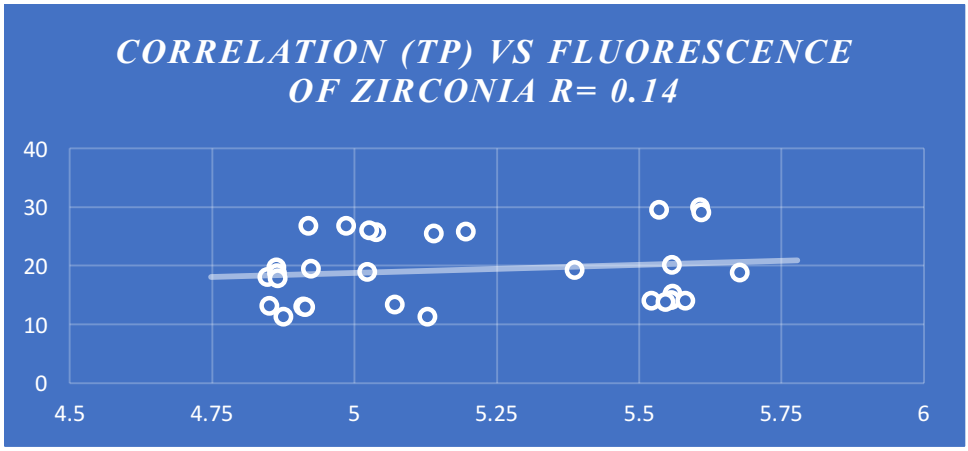

Figure 37

There was no statistically significant correlation between the fluorescence intensity and the CR of Noritake Katana Zirconia samples (p=0.376), (r=-0.171). A scatterplot summarizes the results (Figure 38). Overall, there was no significant linear correlation between the fluorescence intensity and CR.

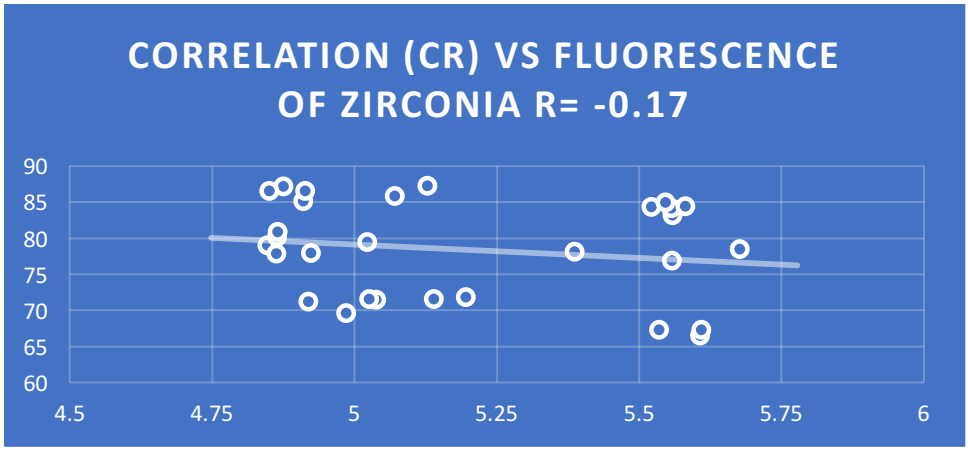

Figure 38

V.3.1.2 Translucency of IPS e.max CAD HT and its correlation to Fluorescence Intensity

A Pearson product-moment correlation coefficient was computed to assess the relationship between the fluorescence intensity of IPS e.max CAD HT samples and their TP and CR values (Table 20).

Correlation between Fluorescence Intensity and Translucency of IPS e.max CAD HT

		Fluorescence	Translucency Parameter	Contrast Ratio
Fluorescence	Pearson Correlation	1	-.216	.295
	Sig. (2-tailed)		.278	.135
	N	45	45	45

Table 20

There was no statistically significant correlation between the fluorescence intensity and the TP of IPS e.max CAD HT samples (p=0.278), (r=-0.216). A scatterplot summarizes the results (Figure 39). Overall, there was no significant linear correlation between the fluorescence intensity and the TP.

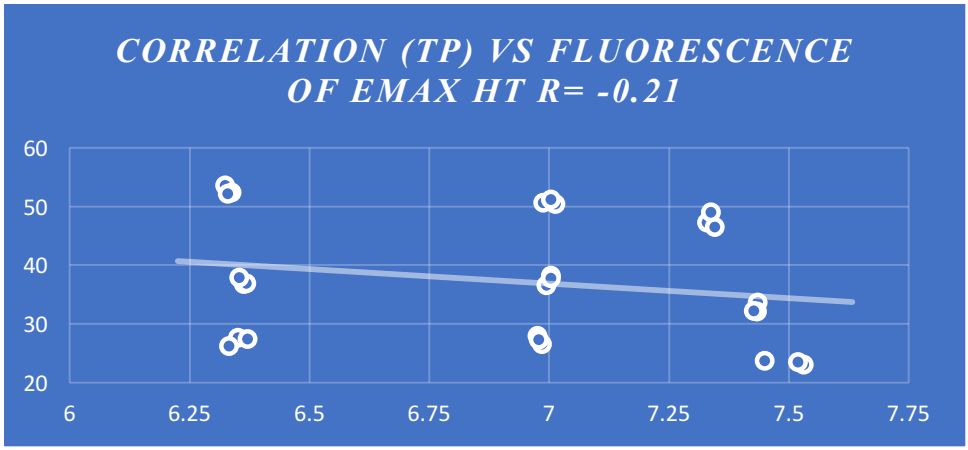

Figure 39

There was no statistically significant correlation between the fluorescence intensity and the CR of IPS e.max CAD HT samples (p=0.135), (r=0.295). A scatterplot summarizes the results (Figure 40). Overall, there was no significant linear correlation between the fluorescence intensity and the CR.

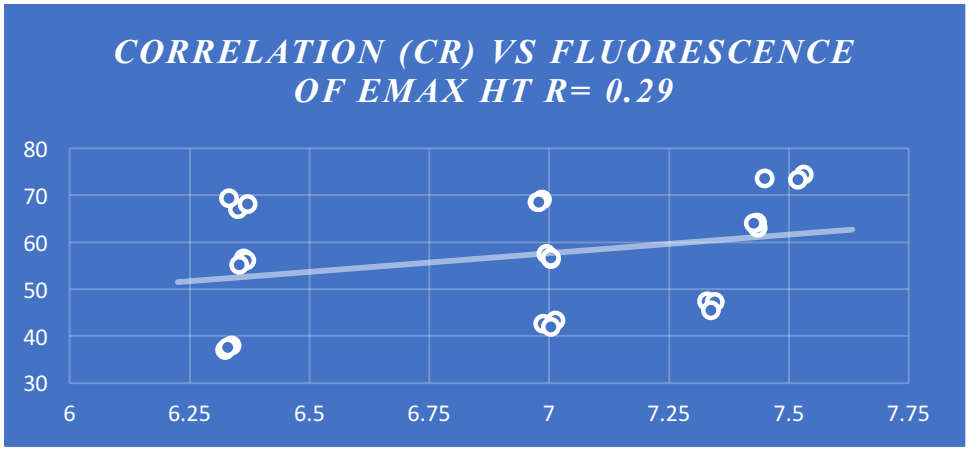

Figure 40

V.3.1.3. Translucency of IPS e.max CAD LT and its correlation to Fluorescence Intensity

A Pearson product-moment correlation coefficient was computed to assess the relationship between the fluorescence intensity of IPS e.max CAD LT samples and their TP and CR values (Table 21).

Correlation between Fluorescence Intensity and Translucency of IPS e.max LT

		Fluorescence	Translucency Parameter	Contrast Ratio
Fluorescence	Pearson Correlation	1	-.674**	.666**
	Sig. (2-tailed)		.000	.000
	N	45	45	45

Table 21

There was a statistically highly significant positive correlation between the fluorescence intensity and the TP of IPS e.max CAD LT samples ($p<0.001$), ($r=-0.674$). A scatterplot summarizes the results (Figure 41). Overall, there was a moderate negative linear correlation between the fluorescence intensity and TP. Increases in the fluorescence intensity were correlated with decreases in the TP.

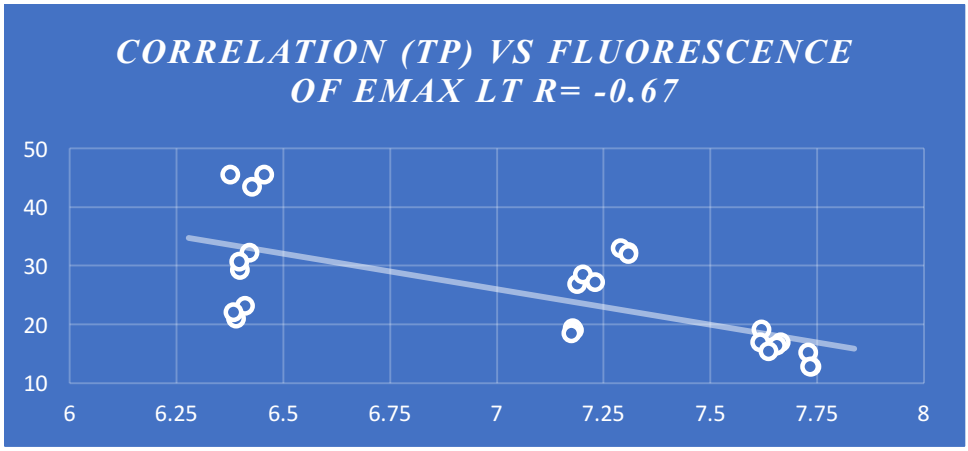

Figure 41

There was a statistically highly significant positive correlation between the fluorescence intensity and the CR of IPS e.max CAD LT samples ($p<0.001$), ($r=0.666$). A scatterplot summarizes the results (Figure 42). Overall, there was a moderate positive linear correlation between the fluorescence intensity and the CR. Increases in the fluorescence intensity were correlated with increases in the CR.

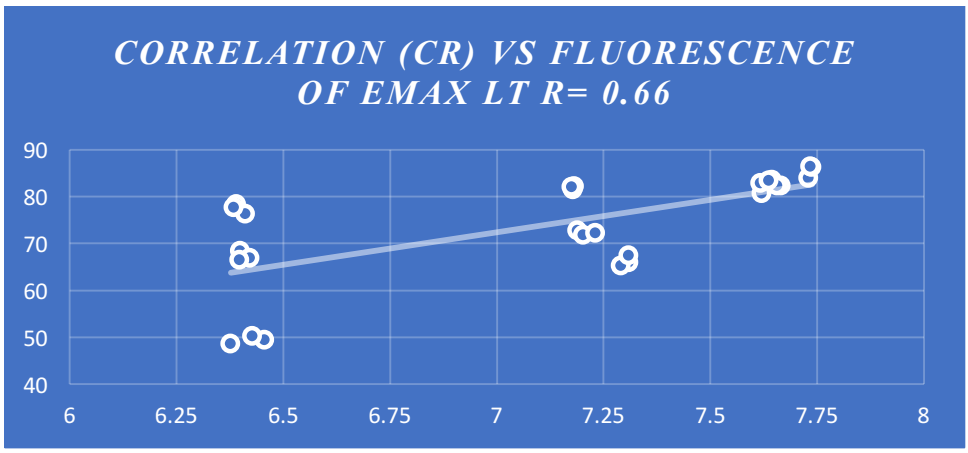

Figure 42

V.3.1.4. Translucency of VITA ENAMIC CAD/CAM Material and its correlation to Fluorescence Intensity

A Pearson product-moment correlation coefficient was computed to assess the relationship between the fluorescence intensity of VITA Enamic CAD/CAM samples and their TP and CR values (Table 22).

Correlation between Fluorescence and Translucency of VITA Enamic CAD/CAM

		Fluorescence	Translucency Parameter	Contrast Ratio
Fluorescence	Pearson Correlation	1	-.861**	.886**
	Sig. (2-tailed)		.000	.000
	N	45	45	45

Table 22

There was a statistically highly significant negative correlation between the fluorescence intensity and the TP of VITA Enamic CAD/CAM samples ($p<0.001$), ($r=-0.861$). A scatterplot summarizes the results (Figure 43). Overall, there was a strong negative linear correlation between the fluorescence intensity and TP. Increases in the fluorescence intensity were correlated with decreases in the TP.

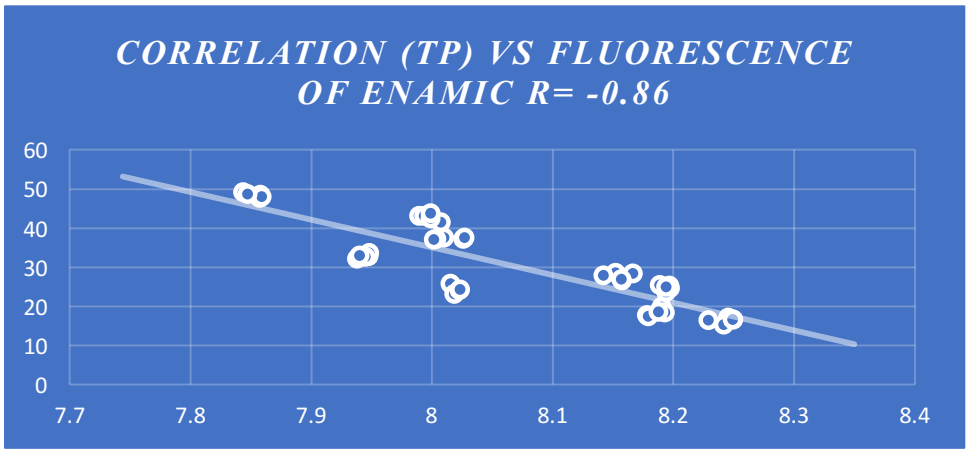

Figure 43

There was a statistically highly significant positive correlation between the fluorescence intensity and the CR of VITA Enamic CAD/CAM samples ($p<0.001$), ($r=0.886$). A scatterplot summarizes the results (Figure 44). Overall, there was a strong positive linear correlation between the fluorescence intensity and CR. Increases in the fluorescence intensity were correlated with increases in the CR.

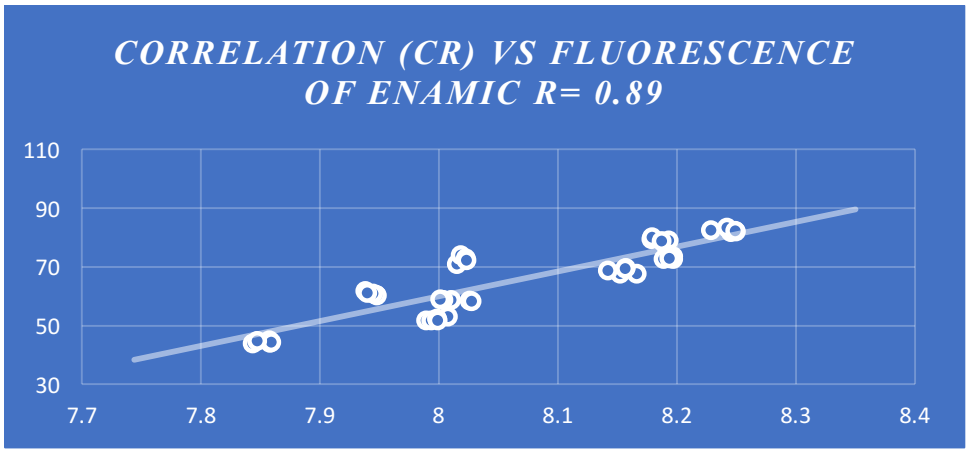

Figure 44

V.4 Specific Aims 4: To assess the effect of fluorescent dyes and glazes on the fluorescence intensity of CAD/CAM ceramic materials.

Null Hypothesis 4:

There is no significant difference in the fluorescence intensity of different CAD/CAM ceramic materials before and after the application of different fluorescent dyes and glazes.

Means and standard deviations of the fluorescence intensity (FI) of Noritake Katana Zirconia before and after application of fluorescent dyes, Lava™ Plus High Translucency Zirconia Effect Shade – Fluorescence (3M), and Colour Liquid Prettau Fluoreszenz (ZZ) are shown in Table 23.

	Initial FI ± SD	**FI after 3M ± SD**	**FI after ZZ ± SD**
Noritake ML A Dark (0.5mm)	4.98 ± 0.07	7.08 ± 0.02	7.23 ± 0.01
Noritake ML A Dark (1.0mm)	4.88 ± 0.04	7.06 ± 0.01	7.44 ± 0.00
Noritake ML A Dark (1.5mm)	4.97 ± 0.15	7.08 ± 0.01	7.42 ± 0.01
Noritake ML A Light (0.5mm)	5.12 ± 0.10	7.22 ± 0.01	7.38 ± 0.01
Noritake ML A Light (1.0mm)	4.92 ± 0.11	7.10 ± 0.00	7.46 ± 0.01
Noritake ML A Light (1.5mm)	4.95 ± 0.12	7.10 ± 0.01	7.44 ± 0.01
Noritake ML HT10 (0.5mm)	5.58 ± 0.05	7.18 ± 0.07	7.36 ± 0.11
Noritake ML HT10 (1.0mm)	5.54 ± 0.14	7.10 ± 0.03	7.47 ± 0.02
Noritake ML HT10 (1.5mm)	5.56 ± 0.09	7.11 ± 0.02	7.47 ± 0.06

Table 23

Means and standard deviations of the FI of CAD/CAM ceramic materials before and after application of fluorescent glazes, IPS e.max Ceram Glaze Paste/Fluo (Ivoclar) and Fluorescent Cad Spray Glaze (Indenco) are shown in table 24.

	Initial FI ± SD	**FI after Ivoclar ± SD**	**FI after Indenco ± SD**
Noritake ML A Dark (0.5mm)	4.98 ± 0.07	7.11 ± 0.00	6.99 ± 0.07
Noritake ML A Dark (1.0mm)	4.88 ± 0.04	6.98 ± 0.03	6.70 ± 0.01
Noritake ML A Dark (1.5mm)	4.97 ± 0.15	6.86 ± 0.01	7.71 ± 0.01
Noritake ML A Light (0.5mm)	5.12 ± 0.10	6.97 ± 0.10	7.76 ± 0.00
Noritake ML A Light (1.0mm)	4.92 ± 0.11	7.26 ± 0.02	7.84 ± 0.01
Noritake ML A Light (1.5mm)	4.95 ± 0.12	7.34 ± 0.00	7.60 ± 0.00
Noritake ML HT10 (0.5mm)	5.58 ± 0.05	7.40 ± 0.01	8.45 ± 0.00
Noritake ML HT10 (1.0mm)	5.54 ± 0.14	7.43 ± 0.00	7.84 ± 0.08

Noritake ML HT10 (1.5mm)	5.56 ± 0.09	7.35 ± 0.00	8.01 ± 0.01
Emax HT A1 (0.5)	7.00 ± 0.02	7.62 ± 0.01	8.52 ± 0.01
Emax HT A1 (1.0)	7.00 ± 0.01	7.51 ± 0.06	8.32 ± 0.02
Emax HT A1 (1.5)	6.98 ± 0.01	7.54 ± 0.03	7.94 ± 0.01
Emax HT A3.5 (0.5)	6.33 ± 0.01	7.68 ± 0.01	8.00 ± 0.01
Emax HT A3.5 (1.0)	6.36 ± 0.01	7.71 ± 0.09	7.90 ± 0.02
Emax HT A3.5 (1.5)	6.35 ± 0.02	7.81 ± 0.01	8.06 ± 0.02
Emax HT BL1 (0.5)	7.34 ± 0.02	7.96 ± 0.00	7.96 ± 0.01
Emax HT BL1 (1.0)	7.43 ± 0.01	7.85 ± 0.00	8.10 ± 0.01
Emax HT BL1 (1.5)	7.50 ± 0.04	7.68 ± 0.01	7.97 ± 0.02
Emax LT A1 (0.5)	7.30 ± 0.01	7.66 ± 0.01	8.09 ± 0.02
Emax LT A1 (1.0)	7.21 ± 0.02	7.46 ± 0.01	7.82 ± 0.01
Emax LT A1 (1.5)	7.18 ± 0.01	7.41 ± 0.01	7.48 ± 0.02
Emax LT A3.5 (0.5)	6.42 ± 0.04	6.81 ± 0.02	7.54 ± 0.01
Emax LT A3.5 (1.0)	6.41 ± 0.02	6.93 ± 0.01	7.79 ± 0.01
Emax LT A3.5 (1.5)	6.40 ± 0.02	7.70 ± 0.01	7.58 ± 0.02
Emax LT BL1 (0.5)	7.63 ± 0.02	7.65 ± 0.01	8.22 ± 0.01
Emax LT BL1 (1.0)	7.65 ± 0.02	7.76 ± 0.02	8.19 ± 0.02
Emax LT BL1 (1.5)	7.73 ± 0.01	7.71 ± 0.00	8.09 ± 0.07

Table 24

The data were subsequently processed and analyzed using the SPSS statistical Software program (IBM SPSS Statistics for Macintosh, Version 23).

Two-way ANOVA ($\alpha = 0.05$) was used to test if there was a statistically significant difference in the fluorescence intensity of CAD/CAM ceramic materials before and after application of fluorescent dye or glaze. Fluorescence intensity was the dependent variable and type of material and type of glaze were the independent variables.

The null hypothesis was rejected ($p<0.001$). There was a highly significant difference between the means of the fluorescence intensity of CAD/CAM ceramic materials before and after the application of fluorescent dyes and glazes.

Tukey's HSD post-hoc test (Table 25) was used to verify which groups did not have a statistically significant mean difference of fluorescence intensity before and after the application of the fluorescent dyes or glazes.

There was no significant difference between means of the fluorescence intensity of IPS e.max CAD LT BL1 before and after application of IPS Glaze Paste/Fluo ($p=0.583$).

All remaining sample group combinations had a statistically highly significant difference ($p<0.001$) in mean of fluorescence intensity before and after application of either dye or glaze.

Multiple Comparisons

Dependent Variable: Fluorescence

Tukey HSD

Material	(I) Glaze	(J) Glaze	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Noritake ML Dark	No Glaze	Ivoclar Glaze	-2.0383*	.10199	.000	-2.3296	-1.7470
		Indenco Glaze	-2.1889*	.10199	.000	-2.4802	-1.8976
		3M Dye	-2.1294*	.10199	.000	-2.4206	-1.8381
		ZZ Dye	-2.4199*	.10199	.000	-2.7112	-2.1286
Noritake ML Light	No Glaze	Ivoclar Glaze	-2.1964*	.05345	.000	-2.3490	-2.0437
		Indenco Glaze	-2.7380*	.05345	.000	-2.8907	-2.5853
		3M Dye	-2.1455*	.05345	.000	-2.2981	-1.9928
		ZZ Dye	-2.4330*	.05345	.000	-2.5857	-2.2803
Noritake ML HT10	No Glaze	Ivoclar Glaze	-1.8327*	.06987	.000	-2.0323	-1.6332
		Indenco Glaze	-2.4567*	.06987	.000	-2.6563	-2.2572
		3M Dye	-1.5424*	.06987	.000	-1.7420	-1.3429
		ZZ Dye	-1.8486*	.06987	.000	-2.0482	-1.6490
e.max HT A1	No Glaze	Ivoclar Glaze	-.4990*	.06924	.000	-.6719	-.3261
		Indenco Glaze	-1.2905*	.06924	.000	-1.4634	-1.1176
e.max HT A3.5	No Glaze	Ivoclar Glaze	-1.2923*	.02774	.000	-1.3616	-1.2230
		Indenco Glaze	-1.5990*	.02774	.000	-1.6683	-1.5297
e.max HT BL1	No Glaze	Ivoclar Glaze	-.4499*	.03226	.000	-.5305	-.3693
		Indenco Glaze	-.6147*	.03226	.000	-.6952	-.5341
e.max LT A1	No Glaze	Ivoclar Glaze	-.3685*	.04685	.000	-.4855	-.2514
		Indenco Glaze	-.7297*	.04685	.000	-.8467	-.6127
e.max LT A3.5	No Glaze	Ivoclar Glaze	-.5077*	.04593	.000	-.6224	-.3930
		Indenco Glaze	-1.1978*	.04593	.000	-1.3125	-1.0831
e.max LT BL1		Ivoclar Glaze	-.0306	.03055	.583	-.1069	.0457

	No Glaze	Indenco Glaze	-.5902*	.03055	.000	-.6665	-.5139

Table 25

One-way ANOVA ($\alpha = 0.05$) was used to test if there was a statistically significant difference between the fluorescence intensity of natural teeth and glazed or dyed CAD/CAM ceramic materials. Fluorescence intensity was the dependent variable and type of material was the independent variable.

The null hypothesis was rejected ($p<0.001$). There was a highly significant difference between the means of the fluorescent intensity of extracted natural teeth, and glazed or dyed CAD/CAM ceramic materials.

Tukey's HSD post-hoc test (Table 26) was used to verify which groups did not have a statistically significant difference in mean of fluorescence intensity when compared to extracted natural teeth.

There was no significant difference between mean fluorescence intensity of:

Natural tooth and Noritake ML HT10 + Ivoclar (p=0.994)

Natural tooth and e.max HT A1 + Ivoclar (p=1.000)

Natural tooth and e.max HT A3.5 + Ivoclar (p=0.997)

Natural tooth and e.max LT A1 + Ivoclar (p=1.000)

Natural tooth and e.max LT BL1 + Ivoclar (p=0.694)

Natural tooth and Noritake ML Light + Indenco (p=0.356)

Natural tooth and e.max LT A3.5 + Indenco (p=1.000)

Natural tooth and Noritake ML Dark + ZZ (p=0.727)

Natural tooth and Noritake ML Light + ZZ (p=0.999)

Natural tooth and Noritake ML HT10 + ZZ (p=0.999)

All remaining sample group combinations had a statistically highly significant difference in mean of fluorescence intensity ($p<0.001$) when compared to extracted natural teeth.

Multiple Comparisons

Dependent Variable: Fluorescence

Tukey HSD

(I) Material	(J) Material	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Natural Tooth	Noritake ML Dark + Ivoclar	.54931*	.06835	.000	.2957	.8029
	Noritake ML Light + Ivoclar	.34031*	.06835	.000	.0867	.5939
	Noritake ML HT10 + Ivoclar	.11414	.06835	.994	-.1394	.3677
	e.max HT A1 + Ivoclar	.03791	.06835	1.000	-.2157	.2915
	e.max HT A3.5 + Ivoclar	-.10928	.06835	.997	-.3629	.1443
	e.max HT BL1 + Ivoclar	-.34263*	.06835	.000	-.5962	-.0891
	e.max LT A1 + Ivoclar	-.06663	.06835	1.000	-.3202	.1869
	e.max LT A3.5 + Ivoclar	.61616*	.06835	.000	.3626	.8697
	e.max LT BL1 + Ivoclar	-.17087	.06835	.694	-.4244	.0827
	Noritake ML Dark + Indenco	.39873*	.06835	.000	.1452	.6523
	Noritake ML Light + Indenco	-.20135	.06835	.356	-.4549	.0522
	Noritake ML HT10 + Indenco	-.50983*	.06835	.000	-.7634	-.2563
	e.max HT A1 + Indenco	-.75359*	.06835	.000	-1.0072	-.5000
	e.max HT A3.5 + Indenco	-.41600*	.06835	.000	-.6696	-.1624
	e.max HT BL1 + Indenco	-.50738*	.06835	.000	-.7610	-.2538
	e.max LT A1 + Indenco	-.42784*	.06835	.000	-.6814	-.1743

	e.max LT A3.5 + Indenco	-.07396	.06835	1.000	-.3275	.1796
	e.max LT BL1 + Indenco	-.73052*	.06835	.000	-.9841	-.4769
	Noritake ML Dark + 3M	.45829*	.06835	.000	.2047	.7119
	Noritake ML Light + 3M	.39120*	.06835	.000	.1376	.6448
	Noritake ML HT10 + 3M	.40446*	.06835	.000	.1509	.6580
	Noritake ML Dark + ZZ	.16774	.06835	.727	-.0858	.4213
	Noritake ML Light + ZZ	.10367	.06835	.999	-.1499	.3573
	Noritake ML HT10 + ZZ	.09828	.06835	.999	-.1553	.3519

Table 26

V.5. Specific Aims 5: To assess the influence of different underlying core materials and luting cements on the fluorescence intensity of CAD/CAM ceramic.

Null Hypothesis 5:

There is no significant difference in the fluorescence intensity of CAD/CAM ceramic materials when different core materials and luting cements are used.

Means and standard deviations of the FI of CAD/CAM ceramic materials with different underlying core materials and luting cements are shown in Table 27.

Material * Core * Cement

Dependent Variable: Fluorescence

Material	Core	Cement	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
Noritake ML Dark	Baseline	Baseline	4.944	.054	4.836	5.052
	Dentin	Multilink	5.609	.054	5.500	5.717
	Build-it	Multilink	5.606	.054	5.498	5.715
	Luxacore	Multilink	5.584	.054	5.476	5.693
	Paracore	Multilink	5.496	.054	5.388	5.604
	Fluorocore	Multilink	5.341	.054	5.233	5.449
		Panavia	5.472	.094	5.285	5.660
		RelyX Ultimate	5.746	.094	5.558	5.934
		No Cement	5.390	.094	5.203	5.578
Noritake ML Light	Baseline	Baseline	4.995	.135	4.724	5.266
	Dentin	Multilink	5.502	.135	5.231	5.773
	Build-it	Multilink	5.499	.135	5.228	5.770
	Luxacore	Multilink	5.576	.135	5.306	5.847
	Paracore	Multilink	5.480	.135	5.210	5.751
	Fluorocore	Multilink	5.426	.135	5.155	5.697
		Panavia	5.549	.234	5.080	6.018
		RelyX Ultimate	6.301	.234	5.832	6.770
		No Cement	6.010	.234	5.541	6.479
Noritake ML HT10	Baseline	Baseline	5.585	.092	5.400	5.770
	Dentin	Multilink	6.553	.092	6.368	6.738
	Build-it	Multilink	6.560	.092	6.375	6.745
	Luxacore	Multilink	6.615	.092	6.430	6.800

	Paracore	Multilink	6.568	.092	6.383	6.753
	Fluorocore	Multilink	6.554	.092	6.369	6.739
		Panavia	6.189	.160	5.868	6.509
		RelyX Ultimate	6.998	.160	6.677	7.318
		No Cement	6.969	.160	6.649	7.290
e.max HT A1	Baseline	Baseline	6.995	.023	6.949	7.041
	Dentin	Multilink	7.145	.023	7.099	7.191
	Build-it	Multilink	7.191	.023	7.145	7.237
	Luxacore	Multilink	7.165	.023	7.119	7.211
	Paracore	Multilink	7.142	.023	7.096	7.188
	Fluorocore	Multilink	7.096	.023	7.050	7.142
		Panavia	7.236	.040	7.156	7.315
		RelyX Ultimate	7.527	.040	7.448	7.607
		No Cement	7.423	.040	7.343	7.502
e.max HT A3.5	Baseline	Baseline	6.349	.059	6.231	6.467
	Dentin	Multilink	6.582	.059	6.464	6.700
	Build-it	Multilink	6.661	.059	6.543	6.779
	Luxacore	Multilink	6.643	.059	6.525	6.761
	Paracore	Multilink	6.603	.059	6.485	6.721
	Fluorocore	Multilink	6.569	.059	6.451	6.687
		Panavia	6.713	.102	6.508	6.917
		RelyX Ultimate	7.277	.102	7.073	7.482
		No Cement	7.130	.102	6.926	7.335
e.max HT BL1	Baseline	Baseline	7.424	.012	7.400	7.449
	Dentin	Multilink	7.564	.012	7.539	7.589
	Build-it	Multilink	7.631	.012	7.606	7.656
	Luxacore	Multilink	7.609	.012	7.584	7.634
	Paracore	Multilink	7.571	.012	7.546	7.596
	Fluorocore	Multilink	7.542	.012	7.517	7.567
		Panavia	7.563	.021	7.520	7.606
		RelyX Ultimate	7.831	.021	7.788	7.874
		No Cement	7.684	.021	7.642	7.727
e.max LT A1	Baseline	Baseline	7.230	.017	7.196	7.264
	Dentin	Multilink	7.286	.017	7.252	7.320
	Build-it	Multilink	7.328	.017	7.295	7.362
	Luxacore	Multilink	7.325	.017	7.291	7.359
	Paracore	Multilink	7.247	.017	7.213	7.281
	Fluorocore	Multilink	7.218	.017	7.184	7.252

		Panavia	7.539	.029	7.481	7.598
		RelyX Ultimate	7.570	.029	7.511	7.629
		No Cement	7.541	.029	7.483	7.600
e.max LT A3.5	Baseline	Baseline	6.408	.035	6.337	6.478
	Dentin	Multilink	6.531	.035	6.460	6.601
	Build-it	Multilink	6.586	.035	6.516	6.656
	Luxacore	Multilink	6.546	.035	6.475	6.616
	Paracore	Multilink	6.482	.035	6.412	6.553
	Fluorocore	Multilink	6.495	.035	6.425	6.566
		Panavia	6.722	.061	6.591	6.835
		RelyX Ultimate	6.991	.061	6.869	7.113
		No Cement	6.871	.061	6.748	6.993
e.max LT BL1	Baseline	Baseline	7.672	.013	7.647	7.697
	Dentin	Multilink	7.748	.013	7.723	7.773
	Build-it	Multilink	7.789	.013	7.764	7.815
	Luxacore	Multilink	7.776	.013	7.751	7.801
	Paracore	Multilink	7.701	.013	7.676	7.727
	Fluorocore	Multilink	7.680	.013	7.655	7.705
		Panavia	7.860	.022	7.817	7.904
		RelyX Ultimate	7.910	.022	7.866	7.954
		No Cement	7.735	.022	7.691	7.779
Enamic 0M1HT	Baseline	Baseline	8.113	.018	8.078	8.148
	Dentin	Multilink	8.221	.023	8.176	8.267
	Build-it	Multilink	8.273	.023	8.227	8.318
	Luxacore	Multilink	8.252	.023	8.206	8.297
	Paracore	Multilink	8.197	.023	8.152	8.243
	Fluorocore	Multilink	8.177	.023	8.131	8.222
Enamic 0M1T	Baseline	Baseline	8.151	.019	8.113	8.188
	Dentin	Multilink	8.246	.024	8.197	8.294
	Build-it	Multilink	8.302	.024	8.254	8.351
	Luxacore	Multilink	8.294	.024	8.246	8.342
	Paracore	Multilink	8.235	.024	8.187	8.284
	Fluorocore	Multilink	8.199	.024	8.151	8.248
Enamic 2m2HT	Baseline	Baseline	7.939	.010	7.918	7.960
	Dentin	Multilink	8.059	.013	8.032	8.086
	Build-it	Multilink	8.100	.013	8.073	8.127
	Luxacore	Multilink	8.082	.013	8.055	8.108

	Paracore	Multilink	8.030	.013	8.003	8.057
	Fluorocore	Multilink	8.004	.013	7.978	8.031

Table 27

The data were subsequently processed and analyzed using the SPSS statistical software program (IBM SPSS Statistics for Macintosh, Version 23).

Three-way ANOVA ($\alpha = 0.05$) was used to test if there was a statistically significant difference in the fluorescence intensity of CAD/CAM ceramic materials when different core materials and luting cements were used. Fluorescence intensity was the dependent variable and type of material, type of core and type of luting cement were the independent variables.

The null hypothesis was rejected ($p<0.001$). There was a highly significant difference between the means of the fluorescence intensity of CAD/CAM ceramic materials when different core materials and luting cements were used.

Tukey's HSD post-hoc test (Table 28) was used to verify which groups did not have a statistically significant mean difference of fluorescence when different core materials and luting cements were used.

All combinations of materials were compared to their baseline values.

There was no significant difference between mean fluorescence intensity of the following combinations when compared to their baseline without underlying materials:

Noritake ML Light combined with dentin and Multilink cement (p=0.189)

Noritake ML Light combined with Build-it and Multilink cement (p=0.195)

Noritake ML Light combined with Luxacore and Multilink cement (p=0.080)

Noritake ML Light combined with Paracore and Multilink cement (p=0.236)

Noritake ML Light combined with Fluorocore and Multilink cement (p=0.386)

Noritake ML Light combined with Fluorocore and RelyX Ultimate cement (p=0.516)

e.max HT A1 combined with Fluorocore and Multilink cement (p=0.064)

e.max HT A3.5 combined with dentin and Multilink cement (p=0.140)

e.max HT A3.5 combined with Paracore and Multilink cement (p=0.078)

e.max HT A3.5 combined with Fluorocore and Multilink cement (p=0.191)

e.max HT A3.5 combined with Fluorocore and RelyX Ultimate cement (p=0.071)

e.max LT A1 combined with dentin and Multilink cement (p=0.327)

e.max LT A1 combined with Paracore and Multilink cement (p=0.998)

e.max LT A1 combined with Fluorocore and Multilink cement (p=1.00)

e.max LT A3.5 combined with dentin and Multilink cement (p=0.270)

e.max LT A3.5 combined with Luxacore and Multilink cement (p=0.146)

e.max LT A3.5 combined with Paracore and Multilink cement (p=0.852)

e.max LT A3.5 combined with Fluorocore and Multilink cement (p=0.707)

e.max LT BL1 combined with Paracore and Multilink cement (p=0.770)

e.max LT BL1 combined with Fluorocore and Multilink cement (p=1.00)

e.max LT BL1 combined with Fluorocore and Panavia cement (p=1.00)

Enamic 0M1HT combined with Paracore and Multilink cement (p=0.052)

Enamic 0M1HT combined with Fluorocore and Multilink cement (p=0.248)

Enamic 0M1T combined with Fluorocore and Multilink cement (p=0.613)

All remaining sample group combinations had a statistically significant difference ($p<0.05$) in mean of fluorescence intensity when different core materials and luting cements were used.

Multiple Comparisons

Dependent Variable: Fluorescence

Tukey HSD

Material	(I) Combo	(J) Combo	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Noritake ML Dark	Noritake ML Dark - Baseline	Noritake ML Dark - Dentin - Multilink	-.66459*	.07640	.000	-.9114	-.4177
		Noritake ML Dark - Build-it - Multilink	-.66235*	.07640	.000	-.9092	-.4155
		Noritake ML Dark - Luxacore - Multilink	-.64029*	.07640	.000	-.8871	-.3935

		Noritake ML Dark - Paracore - Multilink	-.55206*	.07640	.000	-.7989	-.3052
		Noritake ML Dark - Fluorocore - Multilink	-.39689*	.07640	.000	-.6437	-.1500
		Noritake ML Dark - Fluorocore - Panavia	-.44619*	.10805	.004	-.7953	-.0971
		Noritake ML Dark - Fluorocore - RelyX Ultimate	-.52810*	.10805	.000	-.8772	-.1790
		Noritake ML Dark - Fluorocore - No Cement	-.80200*	.10805	.000	-1.1511	-.4529
Noritake ML Light	Noritake ML Light - Baseline	Noritake ML Light - Dentin - Multilink	-.50702	.19103	.189	-1.1242	.1101
		Noritake ML Light - Build-it - Multilink	-.50401	.19103	.195	-1.1212	.1131
		Noritake ML Light - Luxacore - Multilink	-.58136	.19103	.080	-1.1985	.0358
		Noritake ML Light - Paracore - Multilink	-.48551	.19103	.236	-1.1027	.1316
		Noritake ML Light - Fluorocore - Multilink	-.43109	.19103	.386	-1.0482	.1861
		Noritake ML Light - Fluorocore - Panavia	-1.01530*	.27015	.012	-1.8881	-.1425
		Noritake ML Light - Fluorocore - RelyX Ultimate	-.55410	.27015	.516	-1.4269	.3187
		Noritake ML Light - Fluorocore - No Cement	-1.30573*	.27015	.000	-2.1785	-.4329

Noritake ML HT10	Noritake ML HT10 - Baseline	Noritake ML HT10 - Dentin - Multilink	-.96797*	.13052	.000	-1.3896	-.5463
		Noritake ML HT10 - Build-it - Multilink	-.97524*	.13052	.000	-1.3969	-.5536
		Noritake ML HT10 - Luxacore - Multilink	-1.03051*	.13052	.000	-1.4522	-.6088
		Noritake ML HT10 - Paracore - Multilink	-.98294*	.13052	.000	-1.4046	-.5613
		Noritake ML HT10 - Fluorocore - Multilink	-.96926*	.13052	.000	-1.3909	-.5476
		Noritake ML HT10 - Fluorocore - Panavia	-1.38440*	.18458	.000	-1.9807	-.7881
		Noritake ML HT10 - Fluorocore - RelyX Ultimate	-.60399*	.18458	.045	-1.2003	-.0077
		Noritake ML HT10 - Fluorocore - No Cement	-1.41282*	.18458	.000	-2.0091	-.8165
e.max HT A1	e.max HT A1 - Baseline	e.max HT A1 - Dentin - Multilink	-.14982*	.03243	.001	-.2546	-.0451
		e.max HT A1 - Build-it - Multilink	-.19622*	.03243	.000	-.3010	-.0915
		e.max HT A1 - Luxacore - Multilink	-.17060*	.03243	.000	-.2754	-.0658
		e.max HT A1 - Paracore - Multilink	-.14727*	.03243	.001	-.2520	-.0425
		e.max HT A1 - Fluorocore - Multilink	-.10160	.03243	.064	-.2064	.0032

		e.max HT A1 - Fluorocore - Panavia	-.42814*	.04586	.000	-.5763	-.2800
		e.max HT A1 - Fluorocore - RelyX Ultimate	-.24084*	.04586	.000	-.3890	-.0927
		e.max HT A1 - Fluorocore - No Cement	-.53259*	.04586	.000	-.6807	-.3844
e.max HT A3.5	e.max HT A3.5 - Baseline	e.max HT A3.5 - Dentin - Multilink	-.23292	.08327	.140	-.5019	.0361
		e.max HT A3.5 - Build-it - Multilink	-.31259*	.08327	.012	-.5816	-.0436
		e.max HT A3.5 - Luxacore - Multilink	-.29447*	.08327	.022	-.5635	-.0255
		e.max HT A3.5 - Paracore - Multilink	-.25398	.08327	.078	-.5230	.0150
		e.max HT A3.5 - Fluorocore - Multilink	-.22058	.08327	.191	-.4896	.0484
		e.max HT A3.5 - Fluorocore - Panavia	-.78154*	.11776	.000	-1.1620	-.4011
		e.max HT A3.5 - Fluorocore - RelyX Ultimate	-.36395	.11776	.071	-.7444	.0165
		e.max HT A3.5 - Fluorocore - No Cement	-.92877*	.11776	.000	-1.3092	-.5483
e.max HT BL1	e.max HT BL1 – Baseline	e.max HT BL1 - Dentin -Multilink	-.13969*	.01747	.000	-.1961	-.0833
		e.max HT BL1 - Build-it - Multilink	-.20645*	.01747	.000	-.2629	-.1500

		e.max HT BL1 - Luxacore - Multilink	-.18446*	.01747	.000	-.2409	-.1280
		e.max HT BL1 - Paracore - Multilink	-.14672*	.01747	.000	-.2032	-.0903
		e.max HT BL1 - Fluorocore - Multilink	-.11778*	.01747	.000	-.1742	-.0613
		e.max HT BL1 - Fluorocore - Panavia	-.26002*	.02470	.000	-.3398	-.1802
		e.max HT BL1 - Fluorocore - RelyX Ultimate	-.13899*	.02470	.000	-.2188	-.0592
		e.max HT BL1 - Fluorocore - No Cement	-.40698*	.02470	.000	-.4868	-.3272
e.max LT A1	e.max LT A1 - Baseline	e.max LT A1 - Dentin - Multilink	-.05645	.02392	.327	-.1337	.0208
		e.max LT A1 - Build-it - Multilink	-.09861*	.02392	.004	-.1759	-.0213
		e.max LT A1 - Luxacore - Multilink	-.09556*	.02392	.006	-.1728	-.0183
		e.max LT A1 - Paracore - Multilink	-.01756	.02392	.998	-.0948	.0597
		e.max LT A1 - Fluorocore - Multilink	.01154	.02392	1.000	-.0657	.0888
		e.max LT A1 - Fluorocore - Panavia	-.31165*	.03383	.000	-.4209	-.2024
		e.max LT A1 - Fluorocore - RelyX Ultimate	-.30961*	.03383	.000	-.4189	-.2003

		e.max LT A1 - Fluorocore - No Cement	-.34025*	.03383	.000	-.4495	-.2310
e.max LT A3.5	e.max LT A3.5 - Baseline	e.max LT A3.5 - Dentin - Multilink	-.12274	.04970	.270	-.2833	.0378
		e.max LT A3.5 - Build-it - Multilink	-.17816*	.04970	.019	-.3387	-.0176
		e.max LT A3.5 - Luxacore - Multilink	-.13806	.04970	.146	-.2986	.0225
		e.max LT A3.5 - Paracore - Multilink	-.07441	.04970	.852	-.2350	.0862
		e.max LT A3.5 - Fluorocore - Multilink	-.08751	.04970	.707	-.2481	.0731
		e.max LT A3.5 - Fluorocore - Panavia	-.46270*	.07029	.000	-.6898	-.2356
		e.max LT A3.5 - Fluorocore - RelyX Ultimate	-.30546*	.07029	.002	-.5325	-.0784
		e.max LT A3.5 - Fluorocore - No Cement	-.58309*	.07029	.000	-.8102	-.3560
e.max LT BL1	e.max LT BL1 - Baseline	e.max LT BL1 - Dentin - Multilink	-.07607*	.01785	.002	-.1337	-.0184
		e.max LT BL1 - Build-it - Multilink	-.11756*	.01785	.000	-.1752	-.0599
		e.max LT BL1 - Luxacore - Multilink	-.10394*	.01785	.000	-.1616	-.0463
		e.max LT BL1 - Paracore - Multilink	-.02954	.01785	.770	-.0872	.0281

		e.max LT BL1 - Fluorocore - Multilink	-.00823	.01785	1.000	-.0659	.0494
		e.max LT BL1 - Fluorocore - Panavia	-.06302	.02524	.256	-.1446	.0185
		e.max LT BL1 - Fluorocore - RelyX Ultimate	-.18839*	.02524	.000	-.2699	-.1069
		e.max LT BL1 - Fluorocore - No Cement	-.23798*	.02524	.000	-.3195	-.1564
Enamic 0M1HT	Enamic 0M1HT - Baseline	Enamic 0M1HT - Dentin - Multilink	-.10804*	.02862	.005	-.1926	-.0235
		Enamic 0M1HT - Build-it - Multilink	-.15955*	.02862	.000	-.2441	-.0750
		Enamic 0M1HT - Luxacore - Multilink	-.13849*	.02862	.000	-.2231	-.0539
		Enamic 0M1HT - Paracore - Multilink	-.08419	.02862	.052	-.1688	.0004
		Enamic 0M1HT - Fluorocore - Multilink	-.06338	.02862	.248	-.1479	.0212
Enamic 0M1T	Enamic 0M1T - Baseline	Enamic 0M1T - Dentin - Multilink	-.09507*	.03057	.034	-.1854	-.0047
		Enamic 0M1T - Build-it - Multilink	-.15137*	.03057	.000	-.2417	-.0610
		Enamic 0M1T - Luxacore - Multilink	-.14328*	.03057	.000	-.2336	-.0530
		Enamic 0M1T - Paracore - Multilink	-.08446	.03057	.080	-.1748	.0059

		Enamic 0M1T - Fluorocore - Multilink	-.04842	.03057	.613	-.1388	.0419
Enamic 2m2HT	Enamic 2m2HT - Baseline	Enamic 2m2HT - Dentin - Multilink	-.11976*	.01695	.000	-.1698	-.0697
		Enamic 2m2HT - Build-it - Multilink	-.16098*	.01695	.000	-.2111	-.1109
		Enamic 2m2HT - Luxacore - Multilink	-.14235*	.01695	.000	-.1924	-.0923
		Enamic 2m2HT - Paracore - Multilink	-.09115*	.01695	.000	-.1412	-.0411
		Enamic 2m2HT - Fluorocore - Multilink	-.06520*	.01695	.004	-.1153	-.0151

Table 28

One-way ANOVA ($\alpha = 0.05$) was used to test if there was a statistically significant difference between the fluorescence intensity of natural teeth and CAD/CAM ceramic materials with different underlying core materials and luting cements.

Fluorescence intensity was the dependent variable and type of material combination was the independent variable.

The null hypothesis was rejected ($p<0.001$). There was a highly significant difference between the means of the fluorescence intensity of extracted natural teeth and CAD/CAM ceramic materials with different underlying core materials and luting cements.

Tukey's HSD post-hoc test (Table 29) was used to verify which groups did not have a statistically significant difference in mean of fluorescence intensity when compared to extracted natural teeth.

There was no significant difference between mean fluorescence intensity of natural teeth and the following combinations:

e.max HT A1 + Dentin + Multilink (p=0.362)

e.max HT A1 + Build-it + Multilink (p=0.646)

e.max HT A1 + Fluorocore + Panavia (p=1.00)

e.max HT A1 + Fluorocore + No Cement (p=1.00)

e.max HT A3.5 + Fluorocore + No Cement (p=0.103)

e.max HT BL1 + Dentin + Multilink (p=1.00)

e.max HT BL1 + Build-it + Multilink (p=0.979)

e.max HT BL1 + Luxacore + Multilink (p=1.00)

e.max HT BL1 + Paracore + Multilink (p=1.00)

e.max HT BL1 + Fluorocore + Multilink (p=1.00)

e.max HT BL1 + Fluorocore + Panavia (p=0.949)

e.max HT BL1 + Fluorocore + RelyX Ultimate (p=1.00)

e.max LT A1 + Fluorocore + Panavia (p=1.00)

e.max LT A1 + Fluorocore + RelyX Ultimate (p=1.00)

e.max LT A1 + Fluorocore + No Cement (p=1.00)

All remaining sample group combinations had a statistically significant difference in mean of fluorescence intensity ($p<0.05$) when compared to extracted natural teeth.

Multiple Comparisons

Dependent Variable: Fluorescence

Tukey HSD

(I) Combo	(J) Combo	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Natural Teeth	Noritake ML Dark - Dentin - Multilink	1.92305*	.12633	.000	1.4401	2.4060
	Noritake ML Dark - Build-it - Multilink	1.92529*	.12633	.000	1.4423	2.4082
	Noritake ML Dark - Luxacore - Multilink	1.94735*	.12633	.000	1.4644	2.4303
	Noritake ML Dark - Paracore - Multilink	2.03558*	.12633	.000	1.5526	2.5185
	Noritake ML Dark - Fluorocore - Multilink	2.19075*	.12633	.000	1.7078	2.6737

Noritake ML Dark - Fluorocore - Panavia	2.14146*	.18100	.000	1.4495	2.8334
Noritake ML Dark - Fluorocore - RelyX Ultimate	2.05954*	.18100	.000	1.3676	2.7515
Noritake ML Dark - Fluorocore - No Cement	1.78565*	.18100	.000	1.0937	2.4776
Noritake ML Light - Dentin - Multilink	2.02964*	.12633	.000	1.5467	2.5126
Noritake ML Light - Build-it - Multilink	2.03265*	.12633	.000	1.5497	2.5156
Noritake ML Light - Luxacore - Multilink	1.95530*	.12633	.000	1.4723	2.4383
Noritake ML Light - Paracore - Multilink	2.05116*	.12633	.000	1.5682	2.5341
Noritake ML Light - Fluorocore - Multilink	2.10557*	.12633	.000	1.6226	2.5885
Noritake ML Light - Fluorocore - Panavia	1.52136*	.18100	.000	.8294	2.2133
Noritake ML Light - Fluorocore - RelyX Ultimate	1.98256*	.18100	.000	1.2906	2.6745
Noritake ML Light - Fluorocore - No Cement	1.23093*	.18100	.000	.5390	1.9229
Noritake ML HT10 - Dentin - Multilink	.97891*	.12633	.000	.4960	1.4619
Noritake ML HT10 - Build-it - Multilink	.97164*	.12633	.000	.4887	1.4546
Noritake ML HT10 - Luxacore - Multilink	.91638*	.12633	.000	.4334	1.3993
Noritake ML HT10 - Paracore - Multilink	.96395*	.12633	.000	.4810	1.4469
Noritake ML HT10 - Fluorocore - Multilink	.97762*	.12633	.000	.4947	1.4606

	Noritake ML HT10 - Fluorocore - Panavia	1.34275*	.18100	.000	-.1294	1.2544
	Noritake ML HT10 – Fluorocore – RelyX Ultimate	1.34289*	.18100	.000	.6510	2.0348
	Noritake ML HT10 - Fluorocore - No Cement	.56275*	.18100	.000	-.1579	1.2260
	e.max HT A1 - Dentin - Multilink	.38712	.12633	.362	-.0958	.8701
	e.max HT A1 - Build-it - Multilink	.34072	.12633	.646	-.1422	.8237
	e.max HT A1 - Luxacore - Multilink	.36634*	.04953	.000	.1770	.5557
	e.max HT A1 - Paracore - Multilink	.38967*	.04953	.000	.2003	.5790
	e.max HT A1 - Fluorocore - Multilink	.43534*	.04953	.000	.2460	.6247
	e.max HT A1 - Fluorocore - Panavia	.10880	.07096	1.000	-.1625	.3801
	e.max HT A1 - Fluorocore - RelyX Ultimate	.29610*	.07096	.015	.0248	.5674
	e.max HT A1 - Fluorocore - No Cement	.00435	.07096	1.000	-.2669	.2756
	e.max HT A3.5 - Dentin - Multilink	.95010*	.04953	.000	.7608	1.1394
	e.max HT A3.5 - Build-it - Multilink	.87043*	.04953	.000	.6811	1.0598
	e.max HT A3.5 - Luxacore - Multilink	.88855*	.04953	.000	.6992	1.0779
	e.max HT A3.5 - Paracore - Multilink	.92904*	.04953	.000	.7397	1.1184
	e.max HT A3.5 - Fluorocore - Multilink	.96244*	.04953	.000	.7731	1.1518

e.max HT A3.5 - Fluorocore - Panavia	.40148*	.07096	.000	.1302	.6728
e.max HT A3.5 - Fluorocore - RelyX Ultimate	.81907*	.07096	.000	.5478	1.0904
e.max HT A3.5 - Fluorocore - No Cement	.25425	.07096	.103	-.0170	.5255
e.max HT BL1 - Dentin -Multilink	-.03241	.04953	1.000	-.2218	.1569
e.max HT BL1 - Build-it - Multilink	-.09918	.04953	.979	-.2885	.0902
e.max HT BL1 - Luxacore - Multilink	-.07718	.04953	1.000	-.2665	.1122
e.max HT BL1 - Paracore - Multilink	-.03945	.04953	1.000	-.2288	.1499
e.max HT BL1 - Fluorocore - Multilink	-.01050	.04953	1.000	-.1998	.1788
e.max HT BL1 - Fluorocore - Panavia	-.15274	.07096	.949	-.4240	.1185
e.max HT BL1 - Fluorocore - RelyX Ultimate	-.03171	.07096	1.000	-.3030	.2396
e.max HT BL1 - Fluorocore - No Cement	-.29971*	.07096	.013	-.5710	-.0284
e.max LT A1 - Dentin - Multilink	.24538*	.04953	.001	.0560	.4347
e.max LT A1 - Build-it - Multilink	.20321*	.04953	.019	.0139	.3926
e.max LT A1 - Luxacore - Multilink	.20626*	.04953	.016	.0169	.3956
e.max LT A1 - Paracore - Multilink	.28426*	.04953	.000	.0949	.4736
e.max LT A1 - Fluorocore - Multilink	.31337*	.04953	.000	.1240	.5027

e.max LT A1 - Fluorocore - Panavia	-.00983	.04795	1.000	-.1983	.1787
e.max LT A1 - Fluorocore - RelyX Ultimate	-.00779	.04795	1.000	-.1963	.1807
e.max LT A1 - Fluorocore - No Cement	-.03843	.04795	1.000	-.2269	.1501
e.max LT A3.5 - Dentin - Multilink	1.00110*	.03347	.000	.8695	1.1327
e.max LT A3.5 - Build-it - Multilink	.94568*	.03347	.000	.8141	1.0773
e.max LT A3.5 - Luxacore - Multilink	.98577*	.03347	.000	.8542	1.1173
e.max LT A3.5 - Paracore - Multilink	1.04943*	.03347	.000	.9179	1.1810
e.max LT A3.5 - Fluorocore - Multilink	1.03633*	.03347	.000	.9048	1.1679
e.max LT A3.5 - Fluorocore - Panavia	.66114*	.04795	.000	.4726	.8496
e.max LT A3.5 - Fluorocore - RelyX Ultimate	.81838*	.04795	.000	.6299	1.0069
e.max LT A3.5 - Fluorocore - No Cement	.54075*	.04795	.000	.3522	.7293
e.max LT BL1 - Dentin - Multilink	-.21635*	.03347	.000	-.3479	-.0848
e.max LT BL1 - Build-it - Multilink	-.25784*	.03347	.000	-.3894	-.1263
e.max LT BL1 - Luxacore - Multilink	-.24422*	.03347	.000	-.3758	-.1126
e.max LT BL1 - Paracore - Multilink	-.16982*	.03347	.000	-.3014	-.0382
e.max LT BL1 - Fluorocore - Multilink	-.14851*	.03347	.008	-.2801	-.0169

e.max LT BL1 - Fluorocore - Panavia	-.20330*	.04795	.017	-.3918	-.0148
e.max LT BL1 - Fluorocore - RelyX Ultimate	-.32867*	.04795	.000	-.5172	-.1402
e.max LT BL1 - Fluorocore - No Cement	-.37825*	.04795	.000	-.5668	-.1897
Enamic 0M1HT - Dentin - Multilink	-.68956*	.03347	.000	-.8211	-.5580
Enamic 0M1HT - Build-it - Multilink	-.74107*	.03347	.000	-.8726	-.6095
Enamic 0M1HT - Luxacore - Multilink	-.72001*	.03347	.000	-.8516	-.5884
Enamic 0M1HT - Paracore - Multilink	-.66571*	.03347	.000	-.7973	-.5341
Enamic 0M1HT - Fluorocore - Multilink	-.64490*	.03347	.000	-.7765	-.5133
Enamic 0M1T - Dentin - Multilink	-.71412*	.03347	.000	-.8457	-.5825
Enamic 0M1T - Build-it - Multilink	-.77043*	.03347	.000	-.9020	-.6389
Enamic 0M1T - Luxacore - Multilink	-.76234*	.03347	.000	-.8939	-.6308
Enamic 0M1T - Paracore - Multilink	-.70351*	.03347	.000	-.8351	-.5719
Enamic 0M1T - Fluorocore - Multilink	-.66748*	.03347	.000	-.7991	-.5359
Enamic 2m2HT - Dentin - Multilink	-.52729*	.03347	.000	-.6589	-.3957
Enamic 2m2HT - Build-it - Multilink	-.56851*	.03347	.000	-.7001	-.4369
Enamic 2m2HT - Luxacore - Multilink	-.54989*	.03347	.000	-.6815	-.4183
Enamic 2m2HT - Paracore - Multilink	-.49869*	.03347	.000	-.6303	-.3671

	Enamic 2m2HT - Fluorocore - Multilink	-.47273*	.03347	.000	-.6043	-.3412

Table 29

Chapter VI: Discussion

VI.1The Composition of Color

VI.1.1 The Complexity of Color Matching

While every patient case is different, the development of CAD/CAM-based systems has helped clinicians to provide personalized treatments and to promote patient acceptance by increasing the predictability of treatment outcomes, reducing costs and turnaround time of treatment, and preserving the quality and esthetics of dental restorations. These demands have led to the development of a diverse selection of new metal-free ceramic systems through improved shade-matching and natural appearance to increase patient satisfaction. The development of CAD/CAM-based restorative systems has made possible not only prosthesis fabrication using high strength materials but also a less time-consuming process, as full-coverage restorations can be milled chair-side (Beuer et al., 2008). Moreover, CAD/CAM technology are not only applied in the dental office, but also utilized to meet the needs of dental laboratories.

The color of a tooth is built in layers that depend on surface spectral reflectance and light reflectance, diffusion, absorbance, and transmittance. In addition to the hue, chroma, and lightness of color, the translucency, fluorescence, and opalescence are also essential considerations in the restorative material selection (Vanini, 1996; McLaren, 1997; Dietschi, 2001; Baratieri et al., 2006; Pecho et al., 2012). As previously mentioned, dentin is very rich in hue and chroma, while the enamel layer is highly translucent. The intensity of color varies throughout a tooth. It is essential for the clinician and dental technician to manipulate layering techniques for mimicking the complex natural anatomic details and optical properties of teeth to produce life-like, highly esthetic effects (Gamborena & Blatz, 2011). It is also important to understand the variability in perception of color among different observers, as a result of diffuse light transmission that occurs unevenly inside the tooth that eventually penetrates our eyes from the tooth's surface (Arimoto et al., 2010).

Translucency also plays an important role in the understanding of color matching. In dental ceramic systems, translucency is dependent on the thickness, scattering, absorption coefficient, grain size, and pigmentation of the material. Teeth are characterized by varying degrees of translucency that can be illustrated as a gradient between transparent and opaque. There are

different degrees of translucency in enamel and dentin and among the different regions on the tooth. Furthermore, the differences in translucency among restorative materials and when compared to natural teeth suggest the challenges of replacing structures of natural teeth with dental materials.

VI.1.2 The Fundamentals of Fluorescence

Fluorescence, as described in chapter one, is the capability that some objects have to absorb invisible energy from a light source, alter its wavelength, and emit visible light within 10^{-8}sec.[17] A better understanding of the complexity of fluorescence will allow for more natural and esthetic control in fabrication of restorations and will minimize the metameric effect between natural teeth and crowns under various light conditions. It is critical to recognize the changes in fluorescence as a tooth is exposed to multiple factors and conditions, such as caries, necrosis, and age. There is still a lack of literature on the fluorescence intensity of different dental materials and the quantification of fluorescence intensity.

In numerous studies (Stübel, 1911; Ecker et al., 1985; Sensi *et al.,* 2006; Sant'Anna et al., 2007), the properties of fluorescence is highly valued to improve the brightness and richness of the dental restoration and to mimic the natural appearance of teeth. This promotes patient satisfaction of treatment outcome and self-confidence. We are constantly exposed to different light sources with varying ultraviolet components like the sun, mercury-vapor lamps, black-lights, and the flashes used in photography (Monsénégo et al., 1993). If the restorative material fails to have the same fluorescent properties as the natural tooth, it could vary in color under different types of light source, which is commonly known as metamerism. A restorative material that doesn't match the fluorescence intensity of natural teeth can be a big problem for patients who have high esthetic demands, especially those who are frequently exposed to different light conditions (Sensi et al., 2006). For example, black lights can cause restorations with lower fluorescence intensity to appear dark, resulting in unattractive smiles and dissatisfied patients.

Quantifying the fluorescence intensity in dental materials will be advantageous in the selection of different materials involved in the dental treatment, such as the final restorative materials, core materials, luting cements, and fluorescent dyes or glazes. The ultimate goal of this study was to investigate fluorescence intensity in dental materials for CAD/CAM ceramic

restorations and to establish a clinical guideline for material selection of CAD/CAM ceramic prosthesis for optical esthetic achievement.

VI.2 The Methodology of Measuring Fluorescence

VI.2.1 Rationale for Methodology

There have been many color measuring devices available, such as dental colorimeters and spectrophotometers; however, there is little known about fluorescence for natural teeth and restorative materials. Moreover, there is also a limited understanding on the quantification of fluorescence in dental materials and on how to effectively communicate fluorescence in dentistry.

Numerous research studies in dentistry have attempted to use various subjective methods to analyze fluorescence intensity, but lacking the development of a standardized protocol to quantify the intensity values. However, in the fields of physical science, chemistry, biology, medicine and pharmacology, there have been great advancements in this area of study (Lakowicz & Masters, 2008).

The National Institute of Standards and Technology (NIST), a non-regulatory agency of the United States department of Commerce, formerly known as the National Bureau of Standards, recognized the need for standardization and published a guideline for the development of fluorescence intensity standards (Gaigalas et al.,2001). Their current recommendation for quantifying fluorescence intensity is to use a fluorescence spectrophotometer with a photomultiplier tube detector. The NIST recognized that fluorescence spectrophotometers are highly sensitive to environmental factors, such as ambient light and that there are instrument-dependent factors, such as filter characteristics, apertures and lenses of the collection optics. These factors can present discrepancy and unreliability in measurements that are considerable when comparing measured values from different instruments. Their recommendation for achieving repeatable and consistent results is to utilize one material as the control for fluorescence intensity and to analyze control and test subjects with the same instrument, environmental conditions, and excitation and emission spectra (DeRose, 2007).

The lack of a standardized methodology to quantify the intensity values of fluorescence in dentistry led to the objective of this study, which was to formulate a reliable and repeatable

methodology for quantitative analysis of fluorescence intensity in dental materials for CAD/CAM ceramic restorations.

VI.2.2 Analysis of Materials Used

Microplate readers have fluorescence spectrophotometers capable of reading multiple samples, which are placed in plates with multiple wells. The intensity of fluorescence is measured in arbitrary units (A.U.), in which higher units equal to more fluorescence. Based on recommendations of the NIST, we performed all measurements with the same excitation and emission wavelengths. In this study, we used 360nm wavelength for excitation and 430nm wavelength for emission in accordance to previous studies that reported a peak intensity of fluorescence in natural teeth at these settings (Gamborena & Blatz, 2011; Lee et al., 2005; Tani et al., 2003). The wavelength of excitation used also corresponds to the ultraviolet range while the wavelength for emission also corresponds to the blue range. When a natural tooth is irradiated by ultraviolet energy, it emits a blue light.

Although there have been few studies utilizing fluorescence spectroscopy to quantify fluorescence intensity of teeth and dental materials (Tani et al., 2004; Ecker et al., 1985; Monsénégo et al., 1993; Koo et al., 2010; Jablonski et al., 2012; Peplinski et al., 1980; Hartles & Leaver, 1953; Dickson et al., 1952), there have been no previous studies in dentistry utilizing microplate readers.

In order to meet the esthetic demands of a patient and to replicate a tooth with dental materials, it is essential to improve the understanding of form, function and esthetics of a natural tooth. Therefore, we established a standard for fluorescence intensity by quantifying the fluorescence of natural teeth. Moreover, we quantified the fluorescence intensity of dentin by completely removing the enamel from samples to measure only dentin. Previous studies have shown that dentin has a higher intensity of fluorescence than enamel (Benedict, 1928; Dickson et al., 1952; Hartles & Leaver, 1953; Magne & Belser, 2002).

In this study, the fluorescence intensity of empty microplate wells, black modeling compound, water, and glycerin were also quantified to investigate the values that would indicate whether a sample has no fluorescence. The samples should be positioned at the same height in every well of the 6-well plate to maintain repeatable results.

VI.3 Interpretation of Results

VI.3.1 Quantitative Assessment of Fluorescence for Dental Materials for CADCAM Restorations

The lowest fluorescence intensity value measured was approximately seventy-five thousand A.U. for non-fluorescent samples and the highest value was more than two-hundred million A.U. in the most fluorescent sample. Therefore, the Log_{10} reduction of the A.U. was used to facilitate interpretation and statistical analysis. All of the following data mentioned will follow this reduction.

Empty microplates, water, black modeling compound and glycerin were between 4.75 and 5.25, extracted natural teeth were between 7.21 and 7.71, and dentin samples were between 8.09 and 8.35. These findings are consistent with previous studies that indicated a higher fluorescence intensity of dentin when compared to enamel. Although, it was suggested that dentin could be three to four times more fluorescent than enamel (Magne & Belser, 2002; Dickson et al, 1952), our findings demonstrate that dentin can be up to five times more fluorescent than an intact natural tooth.

Different core materials and luting cements were selected to investigate their roles in modifying the fluorescence intensity of CAD/CAM ceramic materials. The selection was based on commonly-used materials in daily practice, which included materials with a diverse range of shades and opacity. The overall purpose of our study was to improve the understanding of fluorescence intensity of CAD/CAM ceramic materials.

From the results, Noritake Katana Zirconia had very low fluorescence intensity measured between 4.88 and 5.58, comparable to distilled water and black modelling compound, both ranging from 4.75 to 5.25. Therefore, this material should only be used with either a fluorescent dye prior to sintering or a fluorescent glaze after sintering. When the fluorescent dye Colour Liquid Prettau Fluoreszenz (ZZ) was used, all zirconia samples appeared in the same range of fluorescence intensity as natural teeth, from 7.23 to 7.47. When Lava™ Plus High Translucency Zirconia Effect Shade – Fluorescence (3M) was used, there was a significant improvement in the fluorescence intensity of all zirconia materials, ranging from 7.06 to 7.22. However, these values are still below the fluorescence of natural teeth.

The application of both IPS e.max Ceram Glaze Paste/Fluo (Ivoclar) and Fluorescent Cad Spray Glaze (Indenco) significantly improved the fluorescence intensity of all zirconia samples.

The Indenco glaze had a better performance on the ML A Dark and ML A Light shades than on the Ivoclar glaze. However, the Indenco glaze should be avoided for the HT10 shade as the samples became extremely fluorescent, some even more than dentin. The fluorescence intensity of HT10 samples with the application of Ivoclar glaze was compatible with the fluorescence intensity of natural teeth.

Previous studies have shown that acid-base dyes could have a detrimental impact on the surface hardness and fracture resistance of zirconia materials (Nam & Park, 2016). There also have been reports that demonstrate increasing wear on the opposing dentition against glazed zirconia when compared to non-glazed (Janyavula et al., 2013). Therefore, it may be recommended to limit the use of acid-base dyes, such as the ZZ dye, to single-unit esthetic anterior cases and to use a water-based dye, such as the 3M, for multiple-unit and full-arch zirconia fixed-partial dentures. Glazing should be limited to the facial aspect of the zirconia restorations, avoiding occlusal and lingual surfaces.

IPS e.max CAD had varying degrees of fluorescence intensity. Overall, darker shades had lower fluorescence intensity values than those of lighter shades. High translucency samples had lower fluorescence intensity values compared to low translucency samples. BL1 samples had an intrinsic fluorescence that ranged from 7.34 to 7.73, which was similar to that of natural teeth. These properties were not affected by the use of different core materials and luting cements. Moreover, their fluorescence was not affected by the Ivoclar Fluo glaze. On the other hand, when Indenco glaze was applied, BL1 samples became highly fluorescent, in the range of 7.96 to 8.22, therefore, the application of this glaze should be avoided in this material. A1 samples ranged from 6.98 to 7.3. Their fluorescence intensity was enhanced to the same levels as natural teeth when a translucent and fluorescent cement was matched with a highly fluorescent core. They also had similar fluorescence intensity to natural teeth when the Ivoclar glaze was applied. Again, Indenco glaze should be avoided as the fluorescence intensity was increased to 8. The A3.5 samples, ranging from 6.33 to 6.42, had the lowest fluorescence intensity among the e.max samples. The HT A3.5 samples showed significant improvements in fluorescence intensity when translucent fluorescent cements were used in conjunction with highly fluorescent cores and when Ivoclar glaze was applied. Again, Indenco glaze should also be avoided for these materials. The only exception for using the Indenco glaze were the LT A3.5 samples. Although there were slight improvements in the fluorescence intensity of these samples in combination of either translucent fluorescent

cements, highly fluorescent cores, or the Ivoclar glaze, the LT A3.5 samples only matched the fluorescence intensity of natural teeth with the application of Indenco glaze.

The samples in the VITA Enamic CAD/CAM group had higher fluorescence intensities than that of natural teeth and was comparable to that of dentin. They ranged from 7.93 to 8.15, with lighter shades exhibiting higher fluorescence intensity than darker ones. These results suggest that these materials should be avoided in the anterior esthetic zone; however, they could be good candidates for core reconstructive materials and for fabricating custom implant abutments cemented to titanium bases.

VI.3.2 The Correlation between Fluorescence Intensity and Optical Properties

When investigating the relationship between fluorescence intensity and optical properties such as L*, a*, b*, TP and CR, we observed that among CAD/CAM ceramic materials, the fluorescence intensity increased as the L* values increased and b* decreased. The decrease in b* also correlated with an increase in fluorescence intensity of natural teeth. Since negative b* values correspond to the blue spectrum of the CIELAB color system, this could explain the emission of blue light from natural teeth when exposed to ultraviolet radiation.

Another possible explanation for these correlations could be the intrinsic properties of fluorescence. In the paper and textile industry, fluorescent agents are used as optical brighteners due to their capability to make orange and yellow materials appear whiter. White shirts become yellow over time due to the fading of these fluorescent agents. Some laundry detergent manufacturers even add fluorescent agents to their products in order to enhance their bleaching capabilities.

Almost a century has passed since Benedict suggested that the fluorescence of teeth correlated with its organic matter (Benedict, 1928). Collagen is fluorescent due to the presence of phenylalanine and tyrosine in its structure (Fujimori, 1966; Crabtree & Fujimori, 1980; Fujimori, 1985; Sionkowska & Kaminska, 1999). Therefore, the fluorescence intensity of natural teeth is most likely associated with the collagen composition in tooth structure. This explains why dentin was more fluorescent than enamel and why the fluorescence intensity of natural teeth was not correlated with the L*, as the collagen composition is independent of color. On the other hand, ceramic and other restorative materials have rare-earth elements such as europium, terbium, cerium, and ytterbium that are added as fluorescent agents. As a result, it is difficult to distinguish

whether a material is more fluorescent because it is lighter in color or a material is whiter and less yellow because it is more fluorescent. This explain not only the higher L* and lower b*, but also the changes in restoration colors when affected by different light sources, a phenomenon known as metamerism. Even though a material may have a lower fluorescence intensity than that of natural teeth, it can still match in color under a neutral light source. However, it will be perceived darker in color compared to natural tooth under light sources from fluorescent lamps, sunlight and backlights. The opposite would also be true if a material had a higher fluorescence intensity than that of natural teeth.

VI.3.3 Layered Samples

When evaluating the compatibility of different core materials and luting cements used with the CAD/CAM ceramic material, the best result was achieved with Fluorocore. Fluorocore, with a mean intensity of 8.24, was the only core material that had a fluorescence intensity similar to that of dentin. Luxacore and Paracore had mean intensities of 7.81 and 7.86 respectively, which are higher than that of natural teeth. Build-it, with a mean intensity of 6.90, was the only core sample that was less fluorescent than natural teeth.

For the luting cements, Multilink had the highest mean (7.59) in fluorescence intensity, followed by RelyX Ultimate (7.48), RelyX Unicem (7.13), and Panavia21 (6.87). The highest increases in fluorescence intensity were observed with RelyX Ultimate and Fluorocore when used underneath the CAD/CAM ceramic. Multilink yielded the lowest increase in fluorescence intensity, most likely because we chose an opaque shade for Multilink. There was no significant difference in the increase of fluorescence intensity of the CAD/CAM ceramic materials when Multilink was used in conjunction with any of the core options. The opaque shade selected for Multilink most likely masked the effect of the core materials. All other luting cements had a better performance when used in combination with Fluorocore. Although the other luting cements evaluated had lower fluorescence intensities than that of Multilink, they had higher translucencies that accentuated the fluorescence of the core material, allowing it to be more perceivable.

VI.4 Clinical Implications

Based on the results of our study, the following considerations are suggested:

1) Katana zirconia should always be immersed in a fluorescent dye before sintering.

2) The Indenco CAD spray glaze should be used for e.max A3.5 shade.
3) The Ivoclar Fluo glaze should be used for e.max A1 shade.
4) A fluorescent glaze was not indicated for e.max BL1 shade, and a regular non-fluorescent glaze should be used.
5) Enamic should be avoided as a final restoration material in the esthetic zone, but could be a good alternative for custom abutments, if used in conjunction with a titanium base.
6) When a core reconstruction is indicated in teeth that are endodontically treated or have extensive caries, the core material should match the fluorescence intensity of dentin. From the samples evaluated, only Fluorocore had a similar property.
7) It is important to choose a luting cement that is translucent and highly fluorescent.

We highly recommend effective collaboration and communication among the dentist, the laboratory technician, and the manufacturers of dental materials. In addition to the information on fracture resistance, fracture toughness, bond strength and color provided by the manufacturer, the information about the fluorescence intensity of each restorative material should also be included by the manufacturer. The clinician should be informed of the exact intensity of each material in order to make evidence-based decisions when selecting restorative materials used in treating each patient.

VI.5 Limitations in Study

One of the shortcomings of any *in-vitro* study is the difference between the clinical indications and the results obtained. The information present is not sufficient to conclude that the teeth measured *in-vitro* would have the same fluorescence intensity as natural teeth *in-vivo*. As previously mentioned, the fluorescence of teeth is related to its organic composition, suggesting that the lack of blood supply and nutrients may decrease the fluorescence *in-vitro*.

Another limitation of our study is the limited selection of materials evaluated, as there are currently a wide range of materials available to be used with CAD/CAM technology. Since we only chose one shade for each luting cement and core material, there is limited information to predict how different shades of the same type of cement would interact with the CAD/CAM ceramic material.

VI.6 Future Studies

As previously mentioned, since only one shade each of core material and luting cement were selected, further studies are needed to better understand the fluorescence behavior of each of these materials when more shades are used within the same material. Additionally, there were no luting cements available that had similar fluorescence intensity to dentin. It would be interesting to evaluate if a better outcome would be possible when luting cements matched the fluorescence of dentin. The use of Enamic for core reconstruction and custom implant abutments could be an interesting field of investigation and perhaps an answer to both the occlusal load and esthetic problems encountered in implant dentistry.

The development of a handheld fluorescence spectrophotometer would be of great value, as there are currently no devices that can be used on patients to evaluate the fluorescence intensity of natural teeth and restorative materials in-vivo. Although we did not quantify the fluorescence of isolated enamel, this could be significant for future studies in order to further investigate the fluorescent behavior of a natural tooth.

Lastly, the same way color communication was improved by implementing perceptibility and acceptability thresholds based on ΔE (Johnston & Kao, 1989; Douglas et al., 2007; Da Silva et al., 2008; Ishikawa-Nagai et al., 2009; Ghinea et al., 2009), we need to further investigate what would be the perceptibility and acceptability thresholds for a variation in fluorescence intensity between samples.

Chapter VII: Conclusions

Based on the findings and within the limitations of this study, we can summarize our conclusions as follows:

1. There was a significant difference in the fluorescence intensity of extracted natural-teeth when compared to dentin, core materials, luting cements, and CAD/CAM ceramic materials.
    a. The fluorescence intensity of dentin was 362% greater than that of natural tooth.
    b. When the fluorescence intensity of core materials was compared to natural teeth, Build-it was 76.7% lower, Luxacore was 91.3% greater, Paracore was 114.5% greater, and Fluorocore was 411.2% greater.
    c. When the fluorescence of luting cements was compared to natural teeth, Panavia was 78.3% lower, RelyX Unicem was 60.4% lower, RelyX Ultimate was 11% lower, and Multilink was 14.9% greater.
    d. When the fluorescence intensity of CAD/CAM ceramic materials was compared to natural teeth, Katana Zirconia A Dark and A Light are 99.7% lower, Katana HT10 was 98.9% lower, e.max HTA3.5 was 93.4% lower, e.max LTA3.5 was 92.5% lower, e.max HTA1 was 71% lower, e.max LTA1 was 50.1% lower, e.max HT BL1 was 21.9% lower, e.max LT BL1 was 38.1% greater, ENAMIC 2M2HT was 155.6% greater, ENAMIC 0M1HT was 281.6% greater, and ENAMIC 0M1T was 316% greater.
2. There was a significant relationship between fluorescence intensity and CIELab values as follows:
    a. There was a moderate negative linear correlation between the fluorescence intensity of natural teeth and their b* value.
    b. There was a strong linear positive correlation between the fluorescence intensity of all CAD/CAM ceramic materials and their L* values.
    c. Katana zirconia and e.max had a strong negative linear correlation between their fluorescence intensity and their b* values.
3. There was a significant relationship between fluorescence intensity and translucency as follows:
    a. There was a moderate negative linear correlation between the fluorescence intensity and the translucency of e.max LT.

b. There was a strong negative linear correlation between the fluorescence intensity and the translucency of Enamic.

4. There was a significant increase in the fluorescence intensity of CAD/CAM ceramic materials when fluorescent dyes or glazes are used.
5. There was a significant increase in the fluorescence intensity of CAD/CAM ceramic materials when fluorescent core materials are used in combination with fluorescent luting cements underneath the ceramic. Overall the best results were achieved when using the most fluorescent core combined with the most fluorescent and most translucent luting cement.

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