IN-VITRO STUDIES ON THE COLOR STABILITY AND MASKING ABILITY OF COMPOSITE CORES AND THE INFLUENCE OF POSTS AND CORES ON THE SHADES OF ALL-CERAMIC SYSTEMS

SWAMINATHAN SETHU

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SWAMINATHAN SETHU

(BDS)

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SUMMARY

The aims of these in-vitro studies are to evaluate the color stability and the substrate color masking ability of the different composite core materials and also to evaluate the influence of post and core color on the final shade of different all-ceramic systems.

The first aim is to evaluate the intrinsic color stability of six composite core materials, they were Bis-Core® Natural, Bisco [BN]; Bis-Core® Opaque, Bisco [BO]; CoreRestore2® White, Kerr [CW]; CoreRestore2® Universal, Kerr [CU]; Core-Flo®, Bisco [BCF]; Ti-Core Natural®, EDS [TC]. Five samples disks of each material were fabricated (5.0 mm diameter and 3.0 mm thickness) according to manufacturers' instructions and stored at 37ºC and 100% humidity throughout the period of the study. Color measurements based on CIELab color system were carried out on all the specimens immediately after fabrication, and at the end of first, second and third week using a spectrophotometer (CM-2600d, Minolta, Japan). The color difference (ΔE*ab) between day 0 and each time interval was calculated. The spectrophotometric data were statistically analyzed using repeat measurement technique and multiple comparisons adjusted with Bonferroni method. The results indicated that all the composite cores studied showed intrinsic color change. The ΔE values of CW were the highest whereas those of BO were the lowest. There was a significant increase in ΔE values for all the composite cores at the end of the first week which was followed by stabilization in the subsequent weeks.

The second aim was to evaluate the translucency and ability of composite cores to mask the color of prefabricated posts. Six composite core materials mentioned above and three prefabricated posts; Aesthetipost (Bisco), C-post (Bisco),

Parapost plus (Whaledent), were selected for the study. Five disks of each composite core were fabricated with three different thicknesses (0.5 mm, 0.75 mm and 1.0 mm thick and 10 mm in diameter) using the moulds. Composite disks of 5 mm thick were used as the control. Disks of Aesthetipost and C-post were fabricated by assembling several posts adjacent to each other with cyanoacrylate embedded in the acrylic base. The disks were then ground and polished to have a flat surface with a sand paper discs. Parapost was fabricated by machining and shaping a block of Titanium-alloy into a disk.

The contrast ratio of composite disks was measured using a spectrophotometer. Subsequently, each composite disk was placed over the post and the color measurement was performed for the various combinations. The measured values were then compared to those that of the control specimens. The color difference (ΔE) was calculated. General linear model and multiple comparisons adjusted with Bonferroni method was used to analyze the data.

According to contrast ratio BO was the least translucent while BCF was the most translucent of the six composite core materials studied. The translucency of the composite decreased as the thickness increased. The masking ability of composite core differed with the color of the prefabricated posts. BO showed the best result in masking the underlying post color with the least ΔE values, whereas BCF exhibited the highest ΔE values. Categories with Parapost exhibited lower ΔE values compared to other posts.

The third aim is to evaluate the influence of the post and core color on the final shade of three all-ceramics of different thickness. The types and fabrication of composite cores (1 mm thick) and post were as mentioned above. The all-ceramics selected were, Empress 2 (Ivoclar, Leichtenstein), Finesse (Dentsply) and Procera

(Nobel Biocare) all of shade A2. Five ceramic disks of 10 mm diameter and three different thicknesses (1.0, 1.2 and 1.5 mm) were fabricated for each of the all-ceramic system. For the control group, composite core disk of each material (5mm thick) was placed under all-ceramic disk without the post and the color was measured using a spectrophotometer (CM2600d, Minolta, Japan). Subsequently, the post, composite core and ceramic disks were stacked and the color measurements were obtained for all possible combinations. Color difference was then calculated by using the control group as the reference. General linear model and multiple comparisons adjusted with Bonferroni method was used to analyze the data.

This study showed that the color prefabricated posts negatively influenced the color of all-ceramic restorations. Parapost exhibited the least influence compared to Aesthetipost and C-post. Procera exhibited the best masking ability of substrate color followed by Empress 2 and Finesse. When placing an all-ceramic crown, the underlying substrate color should be taken into consideration, as it will influence the final shade of the restoration. The thickness of the composite cores and all-ceramic crown has a significant influence in the masking ability. As the thickness of the composite core and the all-ceramic material increased the masking ability of these materials improved.

All the above mentioned findings will aid the clinician to select the appropriate post, composite core and all-ceramic material, to achieve a more esthetic restoration.

CHAPTER 1

1. Review of Literature

1.1 Influence of substrate color on the esthetics of all-ceramic restorations

The importance and relevance of dental esthetics and appearance has been well documented and appreciated by both researchers and clinicians[1]. A successful restoration is the one that exhibits functional stability and esthetic excellence. The importance of esthetics has led to an increase in demand for metal free restorations and has made all-ceramic system, a reliable choice for esthetic dental restorations[2].

All-ceramic materials, composite cores and prefabricated non-metallic posts are found to contribute to achieve an esthetic restoration after an endodontic treatment or after extensive caries removal procedures. The non metallic tooth-colored materials are translucent and thus, the color of abutment teeth can affect the final shade of the all-ceramic crown to a certain degree. The final shade match of an all-ceramic crown is influenced by the color of the underlying substructure components such as post, core, discolored remaining tooth structure and by the all-ceramic material itself[3-6]. This is particularly true in post-endodontic coronal restoration using an all-ceramic system. Since, it has been well documented, that an appropriate permanent coronal restoration after an endodontic treatment improved the prognosis of the treated tooth and a higher success rate was found among endodontically treated teeth with permanent coronal restorations[7-9]. When all-ceramic crowns are indicated after endodontic procedures, it is essential to have a thorough understanding of the factors affecting the color of an all-ceramic restoration in order to achieve a more predictable result.

Significance of translucency of restorative materials

The ability of an all-ceramic crown to blend with its natural counterpart involves the consideration of size, shape, surface texture, translucency and color of the restoration[10], as these factors influence the esthetic value of dental restorations. Since natural enamel has inherent translucency, it is important that all-ceramic restorations reproduce the translucency and color of the natural teeth[11]. However, the advantageous translucency of all-ceramic materials might be susceptible to the negative influence of substrate color. To optimize the esthetics of a restoration, the translucency of the materials used must be either controlled or should be predictable. Non discolored tooth can have more translucent porcelains, whereas discolored tooth or colored substrate should be restored with less-translucent porcelains[11]. Like wise appropriate post and core should be used under all-ceramic crowns to maintain the esthetic integrity of the restoration.

The translucency of an object is the amount of incident light transmitted and scattered by that object. A high translucency gives a lighter color appearance. A more translucent material will show more effect of the backing on the color and appearance. This is true to all-ceramic materials. Translucency of a material is influenced by the scattering of light within the material. The translucency decreases with an increase in scattering within the material. Light scattering in a material is the result of scattering centers that cause the incident light to be scattered in all directions. The scattering centers can be either air bubbles or opacifiers such as titanium dioxide in restorative materials. Another example of a scattering centers are the filler particles in a composite resin matrix which is said to affect the translucency and thereby its masking ability. The effect of scattering is dependent on the size, shape and number of scattering centers. Scattering is also dependent on the difference in refractive indices between the scattering centers and the matrix thus affecting the translucency. Translucency of a material can be measured using contrast ratio measurement technique. This measurement can be performed using transmission spectrophotometers, reflection spectrophotometers, light meters or colorimeters[12].

The translucency of all-ceramic materials and its thickness contributes to its masking ability. It has been identified that all-ceramic cores and its translucency are one of the primary factors in controlling esthetics and is a critical consideration in the selection of materials[13]. This ability differs between the types of all-ceramic materials used in restorative procedures. The same can be applied to composite core materials, as their translucency is vital in masking the color of prefabricated posts after an endodontic procedure.

1.1.1 All-Ceramic Systems

This section briefly reviews some of the currently available ceramics systems based on the method by which they are processed. Ceramics receiving attention include IPS-Empress 2 (Ivoclar AG, Liechtenstein), Finesse (Dentsply), Procera (Nobel Biocare), since these are the all-ceramic material used in this in-vitro study. These three all-ceramic systems where chosen for the study as they represent the various categories of all-ceramic materials and they are considered to be some of the commonly used all-ceramic systems in clinical practice.

Dental porcelains are considered to be the most natural appearing artificial replacement material for missing tooth structure due to their natural appearance and their durable chemical and optical properties[13]. The increasing concern for superior esthetics and biocompatibility and the inability of the metal ceramic to meet this demand, has led to the development of all-ceramic crown materials[14]. With the increase in knowledge about all-ceramic materials and advancement in its technology, it has been advocated as the material of choice for matching the natural dentition[13]. Table 1.1 illustrates some of the more significant development trends in all-ceramics in dentistry.

Table 1.1: Development of all-ceramic materials over time[15]

McLean & Hughes	1965	Developed alumina core material to strengthen dental porcelain
MacCullock	1968	First reported the use of glass casting for dental purposes
Francois Duret	1971	First to consider the automatic production for dental restorations (CAD-CAM technique)
Mo¨ rmann & Brandestini	1980	Developed chairside CAD-CAM system for machining dental porcelain (CEREC)
Sozio & Riley	1983	Cerestore injection-molded core
Horn	1983	Combined etched enamel/porcelain technique to resin bonded restoration
Calamia	1983	Re-introduced the method of etching porcelain, for resin-bonded restorations
Adair and Grossman	1985	Developed the first commercial castable glass
Sadoun	1985	First developed the alumina-infiltrated glass technique
Wohlwend & Scharer	1990	Reported on a technique for pressed glass restorations (Empress)
Andersson & Ogen	1993	Procera – densely sintered alumina core veneered with porcelain
Techceram	1996	Introduction of thermal spray technique into dentistry

Land introduced the first all-ceramic dental crown, eliminating the metal substructure in 1903[16]. The porcelain jacket crown is the traditional, accepted term for all-ceramic crowns used for restoring the entire clinical crown portion of a tooth. These were fabricated with high fusing feldspathic porcelains. The relatively low strength of this type of porcelain prompted the development of alumina-reinforced porcelains in 1965 by McLean and Hughes[16]. Here, the fracture resistance of all-ceramic restorations was significantly improved by adding Al_2O_3 to feldspathic porcelain. These crowns are constructed of a coping or core of a ceramic material containing 40% to 50% alumina with an outer layer of translucent porcelain. These crowns offered better esthetics for anterior teeth than the metal-ceramic crowns.[16] This was followed by Glass-ceramic crown which was introduced in 1968 by MacCulloch. It involved the use continuous glass-molding process for fabrication. The first commercially avalibale castable ceramic for dental use was Dicor[16].

The leucite-reinforced feldspathic porcelain which followed was condensed and sintered like aluminous porcelain and traditional feldspathaic porcelain[16]. It contains a higher concentration of leucite crystals compared with the feldspathic porcelain. It has a moderately opaque core compared to aluminous porcelain core, but it is more translucent than alumina core crowns or glass-infiltrated alumina core crowns. [16] The strengthened all-ceramic system which includes the use of leucite-reinforced porcelains is IPS Empress (Ivoclar, North America, Amherst, New York). The benefits of these strengthening techniques include the substantial improvement in the strength of the restorations, especially with the aluminous core systems, such as In-Ceram (Vivadent, Baldwin Park, California) and Procera All-Ceram (Nobelpharma AB and Sandvik Hard Materials, Malmo, Sweden) owing to the high alumina (Al_2O_3) content[17]. Since then, many other alternative all-ceramic restorative materials with significantly improved mechanical and physical properties have been introduced[11]. Another significant development in all-ceramics was the introduction of the machinable ceramic, Cerec (Siemens, Bensheim, Germany) 1983, this was followed by development of the second generation Cerec in 1994 and the third generation Cerec 3 in 2000[18]. These systems used CAD-CAM for the fabrication of crowns. The other all-ceramic system developed is Techceram all-ceramic system (Techceram Ltd, Shiply, UK). This system relies on a flame spray process and subsequent sintering to create a uniform alumina base layer[18]. However, these strengthening procedures altered the material's optical properties or in other words the translucency of the material which played a significant role in the esthetics of all-ceramic restorations. In an effort to improve the strength and increase the esthetic versatility of all-ceramic crowns, ceramic core also have been developed over which layering can be performed[19]. This procedure provided more control in obtaining the right shade match during restorative procedures. However, the translucency or the masking ability of all-ceramic varied among the various types of all-ceramic materials based on its internal structure.

1.1.1.1 Types of All-Ceramic Systems

In the last decade, numerous ceramic materials for all-ceramic restorations have been developed. Each material uses a different approach to improve the mechanical properties without having a detrimental effect on the esthetic properties of the all-ceramic materials. The various types of all-ceramic materials based on the way they are processed are as follows[20-22] .

1. Sintered porcelains
    a. Leucite-reinforced feldspathic porcelain (Optec HSP – Jeneric Inc)
    b. Alumina based porcelain (Hi-Ceram – Vident, Baldwin Park CA)
    c. Magnesia based core porcelain
    d. Zirconia based porcelain (Mirage II – Myron International, KS)
2. Glass ceramics
    a. Mica-based (Dicor – Dentsply Inc, York, PA)
    b. Hydroxyapatite-based (Ceraperal – Kyocera, San Diego, CA)
    c. Lithia-based
3. Machinable ceramics
    a. Cerec system (Siemens, Bensheim, Germany)
    b. Celay system (Mikrona Technologie, Spreitenba, Switzerland)
4. Slip cast ceramics
    a. Alumina based (In-Ceram – Vident, Baldwin Park, CA)
5. Hot-pressed, Injection-molded ceramics
    a. Leucite based (IPS Empress – Ivoclar USA, Amherst, NY)
    b. Spinel based (Alceram – Innotek Dental Corp, Lakewood, CO)

The following three all-ceramic systems were chosen in this in-vitro study:

<u>1.1.1.1.a Finesse</u>

The Finesse system (Dentsply) is a low-fusing porcelain. One of the basic differences between this formulation and those that have been used for long periods of time is the significant reduction in the firing temperature which is 760°C[23]. This decrease in the temperature imparts an advantageous characteristic feature such as the increase in opalescence, similar to that in the enamel[23]. It also permits the clinician to obtain a highly polished surface at the chairside, thus eliminating the need for reglaze. The other significant difference in Finesse is its leucite content. The leucite content of this low fusing porcelain is only 8% - 10% which three to four time lesser than its high fusing porcelain counterparts. The low-fusing porcelain offers considerably less potential for abrading any materials against which it occludes[23]. This low-fusing porcelain can mimic the proper opacity and translucency ratio commonly associated with natural teeth or ceramic restorations without a metal substrate.

1.1.1.1.b IPS Empress

This system is a hot-pressed, leucite reinforced ceramics were introduced a decade ago[18]. The IPS Empress system (Ivoclar Vivadent, Amherst, NY) can be used for long lasting anterior and posterior esthetic restorations, exhibited wear characteristics essentially identical to those of natural teeth. This system consisted of a pressed glass ceramic in which leucite crystals were nucleated by controlled surface crystallization[24]. This crystallization enables Empress 2 produce a lithium disilicate glass ceramic of 60% crystal content by volume without loss of translucency, as the refractive index of the crystals are similar to that of the glassy matrix. The leucite crystals reinforces the glassy matrix and prevents crack propagation[18].This provided the system with both structural and esthetic excellence required for dental restorations. Restoring natural light transmission and color as well as function, strength, shape and contour of a tooth was thus possible with this system. The leucite reinforced sintered glass ceramic with fluorapatite crystals in Empress 2 is found to be similar in structure and make-up to the apatite crystals inherent to that of the natural dentition. In addition, the material exhibits exceptional flexural strength and fracture resistance[25]. Thus leucite-reinforced glass-ceramic materials have been proven to provide the necessary combination of esthetics and strength to address the contemporary concerns for an enhanced and predictable restorative alternative[26].

1.1.1.1.c Procera

This innovative ceramic was first described by Andersson and Ogen in 1993[17]. Procera is used in both anterior and posterior single unit restorations. Procera AllCeram (NobelPharma, Sweden) has reported a success rate of 94% in a five year clinical study[27]. This crown system is composed of a densely sintered, high-purity aluminum oxide coping that is combined with the low-fusing AllCeram veneering porcelain[17]. It is an all-ceramic system that relies on the production of an alumina core as a substitute for the metal frame work. The core is alumina that has been fired at 1600°C to produce a relatively dense translucent material. The coping is fabricated or milled using CAD-CAM system. The coping is then fired to produce the translucent core upon which a matched porcelain is fired to produce the final restoration[28]. The coping used in this system contributes to both the structural and esthetic integrity of the materials[29]. Usually the coping thickness is 0.6mm which is considered as the standard, but 0.4mm thickness coping is also fabricated for specific low stress bearing areas, especially for restorations in the anterior regions[29].

1.1.1.2 Translucency and thickness of all-ceramics on its masking ability

Esthetics has been one of the fundamental criteria considered in the selection of materials for partial and full coverage restorations. Translucency of the all-ceramic and its color masking ability is considered to be an important factor influencing the esthetics of a restoration. All-ceramic crowns having no metal substructure, permits greater light transmission within the crown, thereby improving the color and translucency of the restoration leading to a more esthetic restoration[6].

The translucency of dental porcelain which influences its masking ability is largely dependent on light scattering. If the majority of light passing through a ceramic is intensely scattered and diffusely reflected, the material will appear opaque. If only part of the light is scattered and most of it is diffusely transmitted, the material will appear translucent. The amount of light that is absorbed, reflected, and transmitted depends on the amount of crystals within the core matrix, their chemical nature, and the size of the particles compared to the incident light wavelength[30]. Particles similar in size to the light wavelength have the greatest scattering effect. Both the chemical nature of the particles and the relative refractive index of the particles to the matrix affect the amount of scattering. Material composed of small particles (0.1µm diameter) is less opaque when visible light passes through. It will have less refraction and absorption in spite of the greater scattering from an increased number of particles. Large particle materials have reduced numbers of particles per unit volume and consequently exhibit less scattering and decreased opacity. For maximal scattering and opacity, a dispersed particle slightly greater in size than the wavelength of light and with a different refractive index to the matrix is required[10]. Appropriate contrast ratio studies on the various types of all-ceramic material will reveal their translucencies and relative masking abilities which will offer predictable esthetics

In clinical practice there are two types of all-ceramic crown systems, a high strength core material and the reinforced ceramic materials without any special core material being used. In the former one, low-translucency alumina is often used as the core material. This system has excellent strength but poor esthetic qualities. In contrast the latter one, like that of the Empress system uses leucite crystal, a material that has good translucency as well as good reinforcement[3].

Many of the greatly improved properties of low-fusing porcelains can be related to the changes made to the leucite component. Leucite is a important component in dental porcelain because it affects the optical properties, thermal expansion, strength and hardness of the porcelain[20]. Leucite's primary function in dental porcelain is to raise the coefficient of thermal expansion, consequently increasing the hardness and fusion temperatures. The leucite content of most of the high-fusing porcelains ranges somewhere between 35 and 40% but Finesse a low-fusing porcelain has only 8-10% percent of leucite content[23].

It is probably necessary to increase the thickness of the porcelain restoration to reduce the effect of the abutment color on the final crown or choose appropriate materials to construct the substructure during restorative procedures[4]. In cases where this thickness cannot be attained, it is effective to make a post using tooth-colored material, such as a porcelain veneered cast post[3] or a tooth colored post(non-metallic post) system. Empress crowns are superior to alumina cores in terms of producing the desired esthetic appearance due to its excellent optical properties. But the thickness of these materials can also influence its ability to mask the substrate color. It has been shown that the color of crowns made from Empress 2 was affected by the abutment color if the thickness of the restoration is equal to or less than 1.5 mm[31].

The value of the color of all-ceramic restoration was greater than a restoration with porcelain veneered on gold alloy. This is probably due to the light reflection from the surface of the metal background. This may also suggest that the porcelain is not as reflective as metal[3]. Because of the effect of the color of abutment tooth, cast posts veneered with tooth-colored porcelain have been introduced, in addition to the conventional cast post systems[32]. Clinical observations of porcelain restorations lead to the hypothesis that certain substructures tend to produce crowns with a lower than expected values or brightness[33]. Hue and chroma discrepancies in a ceramic restoration appear to be less significant and it is easier to modify compared to that of the value, especially when it is too low. Any factor that may influence the color or final shade of all-ceramic crown and especially those that influences the value of a ceramic restoration must be understood in order to be controlled[33]. Since, value (brightness) is a more important dimension than hue and chroma, any variation in value is more readily perceived[34]. The value of an all-ceramic restoration can be influenced by the color of the post and core systems, thus affecting the esthetics of the restorations.

1.1.2 Composite core build-up systems

Prefabricated posts are used more commonly than custom-cast posts, so it is important to have an understanding of the core build-up materials used[35]. The primary objective of the post and core build-up is to replace the missing coronal tooth structure due to fracture, dental caries or after endodontic treatment and also to provide the required retention and resistance form for the final restoration[5, 36] .The main function of the core is to provide a visible and accessible platform to improve the transfer of forces from the final restoration during function[36-38]. The post and core materials also should be esthetically compatible. When designing a porcelain fused to metal crown, the core esthetics is of least of concern. The metal of the crown covered and masked the color of both the post and core completely. However, when all-ceramic restorations with supragingival margins are used a metallic or dark post or core will be readily visible through these semi-translucent restorations. This is an esthetic compromise that most patients will not accept.

The need to replace lost tooth structures with materials that best approximate the individual tooth structure both structurally and esthetically has led to the development of new polymer based materials[39]. Amalgam, resin composite and glass ionomer are commonly used as core buildup materials[40]. Composite resin has a long history of use as core materials due to its ease of manipulation. It is available in light-cure, auto-polymerized, and dual-cure formulations, and it comes in tooth colors for anterior use and contrast colors for posterior use[35]. An evaluation of the physical and mechanical properties of core materials reported in the literature showed that many composite based core materials possess the compressive and tensile strengths of dental amalgam and proves to be a better choice as core build-up materials[39, 41]. The use of direct core build-up materials especially composite resin based core is likely to increase in coming years. The ease of use of direct materials such as amalgam and composite based core materials will most certainly dominate product selection[39]. Dental composites have been considered acceptable restorative materials for anterior applications due to their color-matching ability and the absence of mercury[42]. Although composite is as strong as amalgam it has only recently been accepted as a good core material. With the appropriate bonding system, predictable results can be accomplished with the composite core.

When esthetics is of primary concern, the selection of appropriate restorative materials becomes an important consideration. Selecting the proper post and core system for a specific clinical situation requires an evaluation of the various components and interfaces of the system[43]. Therefore, in creating optimal esthetic harmony with the surrounding dentition, the underlying restorative material should have similar optical properties as natural tooth structure or in other words the underlying restorative material can directly influence the esthetics of the restoration.

One particular aspect of composite core build-up materials that should be well understood is its capacity to mask color of the underlying substrates such as discolored remaining tooth structure and prefabricated non-tooth colored posts.

Prefabricated posts that are dark, black or opaque can be partially masked if the post is embedded in a tooth-colored core material[44]. Prefabricated posts with composite cores have become the most popular methods for post and core tooth buildups[45]. These posts and cores are faster and easier to construct than custom cast posts and cores and they provide acceptable strength and serviceability at relatively low cost to patients[45].

The masking ability of the composite is directly related to its translucency. The translucency of composite materials is affected by such factors as the particle size and content of the filler used, the refractive indexes of the fillers and the matrix and the pigment they contain[4]. The materials are composed of numerous inorganic particles and a surrounding matrix phase. The higher the refractive index differences between the two phases, the greater the opacity of the materials, due to multiple reflection and refraction at the matrix particle interfaces. Opacity decrease might be caused by a change of refractive index of the matrix phase of the materials, leading to a decrease in the refractive index difference between the particles and matrix[4, 46]. It is also known that light scattering and contrast ratio are affected by the content and particle size of the filler. Fillers in dental composites influence the strength, stiffness, dimensional stability, radiopacity, handling properties and esthetics of the restorations. One of the most important considerations in the selection of filler is the optical characteristics of the composite. The monomer resins used in dental composites have a refractive index of approximately 1.55. Fillers with refractive indices which differ greatly from this value will cause the composite to appear optically opaque, creating an esthetic problem. Glass fillers can have refractive indices ranging from 1.4 to 1.9, which influences the translucency of these materials.

The composite core materials are strong, can be used in thinner section or increments enabling ease in building up of the core. It sets (light or chemically cured) faster than other conventional direct core materials and does not always need a matrix for contouring. It is biocompatible and more esthetic than other core buildup materials. It can be used both in anterior and posterior restorations. However, it is highly technique sensitive requiring effective isolation[38].

The composite core has excellent adaptation to the remaining tooth structure. As it involves a direct chairside procedure, it is simple and predictable. The composite core will form strong bonds to remaining tooth structures, bondable posts, resin cements and ultimately, the final restoration[36]. Composite resin is easy to prepare to an ideal foundation for the final restoration, and it is available in a variety of colors for maximum esthetic benefit[36]. Thus, composite cores materials play a pivotal role in postendodontic all-ceramic restorations providing both function and esthetics.

1.1.3 Endodontic Post Systems

The endodontic post system is a vital component of a coronal restoration for an endodontically treated tooth. It serves as an anchor for the core and crown of the treated teeth, especially in situations were a major part of the supra-gingival tooth structure is lost due to dental caries or trauma and has to be replaced with artificial prosthesis. The principal function of an endodontic post is to retain the coronal restoration of the endodontically treated tooth and to protect the treated tooth by directing the occlusal and lateral forces more apically, thus providing sufficient rigidity under load. This redistribution also helps to maintain marginal integrity of the final restoration.

Attempts to restore pulpless teeth using post and crowns have been reported for more than 200 years[47]. In 1728 Pierre Fauchard described the use of tenons, which were metal posts screwed into the roots of teeth to retain bridges. In the mid 1800s wood replaced metal as the post material and the pivot crown, a wooden post fitted to an artificial crown and to the canal of the root were reported[48]. In the late 19th century, the Richmond crown, a single piece post retained crown with porcelain facing, was engineered to function as bridge retainer[48]. During the 1930s the custom cast post and core was developed to replace one-piece post crowns[48]. This was later followed by an alternative and currently more popular method, the prefabricated post and core system[49]. The different kinds of posts based on the type of material used. They can be categorized as follows:

I Cast post: (gold alloys, noble or base metal alloys)

II Prefabricated post:

(i) Metallic – (Pl-Au alloys, Pd, Brass, Ni-Cr alloys, CpTi, Ti alloys)

(ii) Nonmetallic – (Composites or Resin reinforced, Ceramics)

Traditional prefabricated metal posts are made of Platinum-Gold alloy, Palladium, Brass, Ni-Chromium alloy(stainless steel), pure titanium and its alloys and chromium and its alloys[49, 50]. The potential for adverse tissue responses to the nickel in stainless steel has motivated the use of Ti alloy[51, 52]. Metal posts (Ti, Platinum alloys) are most commonly used due to their superior physical properties and excellent biocompatibility. Unfortunately their metallic color and complete opacity lead to grayish-blue discoloration and shadowing both of the cervical aspects of the gingival and the root. When all-ceramic restorations are used, a metal core will alter the optical properties of the overlying restoration. This may result in severe aesthetic compromise in anterior teeth[53]. Apart from the undesirable esthetics, metal post is said to increase the risk of root fracture and removal of metal post system was also proven to be difficult[54]. These setbacks in the metallic post systems led to the evolution of prefabricated non-metallic post systems.

Post selection is the primary factor that influences the prognosis or success of the endodontic post system and eventually that of the treatment. The selection of dental materials for clinical implementation should be based on physiochemical properties, biocompatibility, handling characteristics, esthetics and economy. Considering the factors, the prefabricated non-metallic post system fulfills the above requisites to be the post system of choice today. Though prefabricated metal posts offered some advantages over cast posts, but when used under all-ceramic crowns can create a significant esthetic concern due to "shine through". Prefabricated non-metallic post systems have been developed to overcome this esthetic limitation of traditional cast-metal and prefabricated metal posts without compromising on its functional properties[55].

There are several non-metallic alternatives to the metal post that offer functional, as well as esthetic benefits. They fall into several categories and the following are some of the various prefabricated non metallic post or fiber reinforced post systems:

a. Carbon fiber post- Composipost, C-post
b. Carbon fiber core surrounded by quartz sheaths - Aesthetipost
c. Quartz fiber post – Aesthetiplus, Parapost fiber white, Fiberkor
d. Ribbon fiber material post – Ribbond post
e. Ceramic or Zirconia post – Cosmopost, Cerapost.

One of the first viable alternatives was the carbon fiber post (C-post, Bisco) made from unidirectional pretensed carbon fibers in an epoxy matrix[56]. Though the original version of the carbon fiber post would not corrode like metal and offered exceptional functional benefits, it was black and did not provide any significant esthetic advantages over a similarly sized prefabricated metal post[56]. In an effort to overcome this disadvantage, several tooth-colored posts have been developed[35]. Improved versions of the carbon fiber post were offered with a white quartz sheath surrounding a black carbon fiber core (Aesthetipost, Bisco). The white coating on the post would effectively eliminate the shine-through, but on the whole it was realized that most of the light transmission through the root and gingival complex was still diminished [56].

Though these posts are white or tooth colored, they are fairly opaque which might influence the esthetics if used under all-ceramic restorations and its influence on the esthetics in the gingival region. Gingival tissues that are not influenced by the color of the root facilitate the use of composite supported by titanium or carbon posts or the use of a metal-ceramic post and core systems. Conversely, a clinical condition with high lip line accompanied by thin gingival tissue requires the use of more esthetic posts to optimize the esthetic effect while maintaining an adequate level of strength[57].

The resin fiber post is more similar in its characteristics to natural dentinal structure than any previously used post. It has excellent transverse strength and dissipates much of the stress placed on the finished restoration, transmitting only a small fraction of these forces to the dentinal walls. The fiber post bonds to tooth structure, core materials, and resin cements. Apart from providing better esthetics, the other major advantage of non-metallic fiber post is that the technique for removing them is much simpler in the event of fracture or retreatment for an endodontically managed tooth[54]. With glass-fiber posts both the above mentioned advantage can be achieved, whereas with zirconia post the removal post still proves to be more difficult[54]. Based on the above mentioned advantages, the tooth colored fiber posts are preferred for dental restorations, especially when all-ceramic coronal restorations are planned [36, 58].

1.1.4 Luting agents

The development of all-ceramic restorations has brought about a substantially different perception concerning luting agents. Zinc phosphate cement has been the standard for nearly a century. However, its overall properties are found to be inappropriate for certain types of restorative systems and its properties certainly falls short for all-ceramic restorations, as it may cause bulk fractures. The luting cement should primarily exhibit sufficient flexural modulus and fracture toughness. The other properties desired include color stability and fluoride release to offer protection against secondary caries. The luting agent should also possess dual-cure potential and multiple viscosities for use with different type of restorations[23].

Resin based luting cements bonds better with the dentin and enamel and with other restorative materials than zinc phosphate. They exhibit high bond strength to tooth, metal and ceramic. It is easy to use and ensures predictable results[36]. The all-ceramic crown cemented with resin cement is found to be functionally more reliable, with a low incidence of post cementation sensitivity and interfacial microleakage. The color of luting agent was found to have very minimal influence on the final shade of the all-ceramic restoration[31]. This fact suggests that luting agent should not be considered to mask underlying substrate color, nor will it influence the final shade.

1.2 Evaluation of substrate color influence.

1.2.1 Color Science

Color is one of the most important determinants of dental esthetics[59]. Recently, increasing emphasis is being placed on "esthetic" dentistry, essentially on the invisible repair of tooth structure. The "invisibility" mentioned requires the optical properties of color, gloss and translucency of tooth substance be reproduced by the restorative material, thus bringing out a perfect match between the restoration and the remaining natural tooth. This demands a better understanding about the science of color.

The committee on Colorimetry of the Optical Society of America in 1922 defined color "as the general name for all sensations arising from the activity of the retina of the eye and its attached nervous mechanisms, this activity being, in nearly every case in the normal individual, a specific response to radiant energy of certain wavelength and intensity"[60]. Light energy evokes responses in different sets of cortical cells according to its wavelength that enable us to distinguish objects in terms of their spectral reflectance. Color is a product of the interpretation of a physical stimulus by our brain. The factors and conditions relevant to color matching involve defining the nature and dimensions of color; quantification of color and color differences. Knowledge of these factors would equip the clinician to deal with issues regarding color matching in clinical practice.

Color has three primary attributes, which are also referred to as dimensions. The three corresponding dimensions of color are Hue, Value and Chroma. Thus color can be described with almost the same precision as solid bodies. These attributes are expressed in a three dimensional space. To allow accurate specification of object colors and color differences, uniform color spaces were suggested. The various color spaces recommended over time are as follows,

1. Munsell color order system (1905)
2. Jud Uniform Chromaticity Scale (1935)
3. MacAdam u, v diagram (1937)
4. RUCS system/ Rectangular uniform chromaticity diagram (1939)
5. Adams Chromatic Value and Chromatic Valence System (1942-43)
6. Saunderson-Milner's Zeta Scale (1946)
7. Adams-Nickerson Color Scales (1950-52)
8. Glasser Cube Root Space (1958)
9. Hunter Color Scale (1958)
10. Friele r, g, b Color Scale (1961)
11. FMC Matrices (1967)
12. CIE U*V*W* Color Space (1964)
13. CIELUV and CIELAB Color Spaces (1976)

Of the numerous color systems, we shall discuss the two most widely used color systems in dentistry and other color related industries, the Munsell and CIELAB color systems[61]. The Munsell color order system was used in dentistry and is replaced by the CIELAB color system which is followed till date[62, 63].

1.2.1.1 Munsell color system

It was a widely recognized and used color order system, which has a human observer as its "standard observer". This system uses a three-dimensional system with hue, value and chroma as coordinates. In this system Hue describes and differentiates one color from another, for example red from green or blue. Hue is also associated with the wavelengths of the light observed. Chroma describes the degree or amount of hue present or the intensity of the color. Value is the proportion of black and white in the hue and distinguishes a light from a dark color. In the Munsell system, low values refer to dark colors and high values refer to light colors[64]. Value is the most important color factor in tooth color matching.

1.2.1.2 CIELAB color system.

This color order system is described by the Commission Internationale de I'Eclairage / International Commission on Illumination (CIE) system. The CIELAB color system is an accepted method for differential color measurement in dentistry[6, 63]. In the CIE system the three dimensions of color are computed mathematically, with dominant wavelength as the Hue, excitation purity as Chroma, and luminous reflectance as Value[64].

CIE recommended color spaces are the ones commonly used in colorimetry. CIE recommended three dimensional uniform color spaces – CIELAB and CIELUV in 1976. These are called CIE 1976 (L*, a*, b*) color space or CIELAB color space and CIE1976 (L*, u*, v*) color space or CIELUV color space. The CIELAB color space is a modified version of the Adams-Nicekrson formula (ANLAB) recommended in 1976. Three attributes L*, a*, b* in CIELAB color space are obtained by non-linear transformation of CIE tristimulus values[65]. L* represents lightness i.e., it is represented in the vertical axis with white (L=100) at the top and black (L=0) at the bottom (Fig 1a). The coordinates a* represents redness (a+) – greenness (a-) and b* represents yellowness (b+) – blueness (b-), as shown in (Fig 1a). The total color difference is derived using the formula $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. In addition to the overall color difference ΔE, the difference in individual parameters between the standard and a sample can also be estimated. These parameters may indicate some specific visual difference such as;

$\Delta L < 0$ or > 0, the sample is darker or lighter respectively,

$\Delta a^* < 0$ or > 0, the sample is greener or redder respectively,

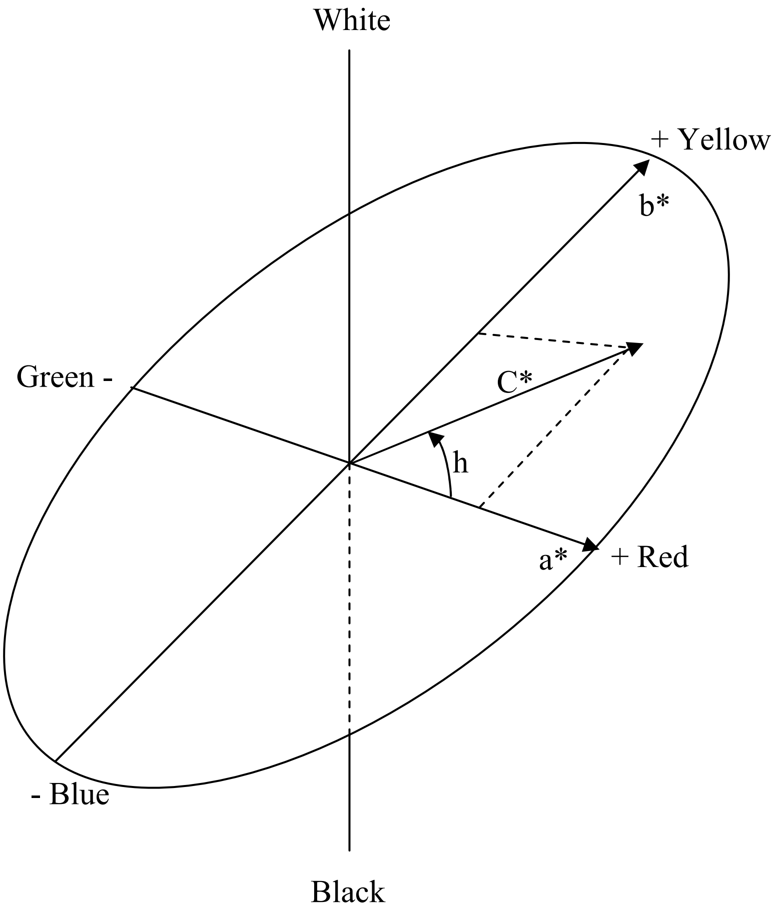
$\Delta b^* < 0$ or > 0, the sample is blue or yellow respectively.

In order to bring parity with the Munsell color order system, two additional parameters are defined as follows: metric hue angle H_{ab} and metric chroma $C_{ab.}$ Hue angle is expressed on a 0-360° scale (Fig 1a). Both CIELUV and CIELAB formulae are plotted on rectangular coordinates. Lightness L* function is the same for both color spaces and the chromaticities are expressed by u*-v* coordinates and a*-b* coordinates for CIELUV and CIELAB color scales respectively.

By projecting the tristimulus values on to the unit plane, color can be expressed in a two dimensional plane. Such a unit plane is known as the chromaticity diagram. The color can be specified by the chromaticity co-ordinates (x, y). The diagram using the chromaticity coordinates (x, y) is referred to as the CIE 1931 chromaticity diagram. This diagram is very non-uniform in terms of color difference. To improve this in 1960, CIE defined an improved diagram – CIE1960 (u, v) this was further improved to form 1976 uniform chromaticity scale (UCS) diagram, with its chromaticity coordinate (u', v'). This chromaticity scale is significantly more uniform that the (x, y) diagram, yet it is still far from perfection. Presently the CIE color space system is recommended and widely used in colorimetry[66].

Current photometric and colorimetric instruments using this color system are capable of reliably quantifying color of both extracted teeth and restorative materials for better understanding.

Fig 1a: Commission Internationale de I'Eclairage (CIE)LAB color space relationship



1.2.2 Colorimetry

The goal of most color measurement is to accurately estimate what an observer sees. The measurement of color must be defined in such a way that the results correlate accurately with what the visual sensation of color is to a normal human observer. Colorimetry is the science and technology used to quantify and describe physically the human color perception. The basis for colorimetry was established by CIE (Commission Internationlae de I'clairage) in 1931 based on visual experiments. Even though the limitations are well recognized, the CIE system of colorimetry remains the only internationally agreed metric system for color measurement. All the official color-related international standards and specifications use the CIE system, including the American Dental Association[62, 63]. The CIE system works well in most cases, but one should know the assumptions and limitations in visual conditions where the CIE system is defined.

1.2.2.1 Instruments

There is an alternate method for describing color that does not rely on human perception. An instrument, such as a spectrophotometer, uses a photocell as the observer. With this instrument, color is described in physical terms[64]. Since, color assessment is a complex psychophysiologic process, which is subject to numerous variables; an instrument based colorimetric evaluation system is more reliable. Inconsistencies in a person's ability to reliably select color matches are well documented. As a result of the subjective nature of color perception, instrumental colorimetric techniques have been used within the dental field to achieve quantitative evaluation of color differences[6].

In contrast to instrumental assessment of color difference, visual comparison of colors is limited to determination of a perceptible mismatch and of the acceptability of mismatch. Differences among observers as to what represents perceptible and acceptable color differences has prompted the scientific community to determine correlations between instrumental and visual assessment of color[67].

The human eye is a highly versatile detector of light and color. An observer can perceive chromatic attributes and various geometric factors (direction, texture, shape and many others) simultaneously. Any instrument till now is far behind in versatility. It can measure only one attribute at a time. In other words, we need several instruments to measure various aspects of visual perception. However, visual assessments are qualitative, debatable, and variable with viewing conditions and are observer-dependent, whereas instrument assessments are quantitative, faster, reliable and reproducible. The foundation stone for instrumental color measurement was proposed by CIE in 1931 by defining standard observer and illuminants. The first generation instruments could measure point to point reflectance only to be followed by hand calculations to evaluate the color difference based on the values obtained. The second generation instruments developed between 1936 and 1949 utilized mechanical calculators. The third generation instruments were much faster using analog computers. In the late seventies, personal computers revolutionized the fourth generation color measurement instruments[68].

Basically there are three types of colorimetric instruments in use; they are the colorimeter, spectrophotometer and spectroradiometer. However, the measuring instruments can be broadly classified according to whether it measures geometric or chromatic attributes of an object.

<u>Classification of color measuring instruments[68]</u>

1. Geometric attributes

   Gloss, haze, texture, etc

2. Color attributes

   a. Physical analysis

      i. Spectroradiometer (illuminant mode)

ii. Spectrophotometer (object mode – reflectance & transmittance)

b. Psychophysical analysis – colorimeter (object mode – reflectance & transmittance)

Color measuring instruments may be designed to measure physical attributes (like intensity of light sources or reflectance/transmittance of objects) or psychophysical attributes (i.e. some correlates of visual perception). However by interfacing with computer, physical analysis instruments can also provide psychophysical measures. On the other hand, psychophysical analysis instruments can provide only limited information.

1.2.2.1 a Colorimeters

There are two types of colorimeter – visual and photoelectric. The earlier visual colorimeters were basically visual absorptionmeters which compare the color of the sample. The newer ones known as true colorimeters were able to render visual equivalence or psychophysical estimation and it defines color in its own primaries. Visual colorimeters were replaced by photoelectric colorimeters, which produced faster and more reproducible color measurements. The photoelectric colorimeters directly measured colorimetric quantities for one illuminant and observer with the help of broad band filters and photoelectric cells[68].

1.2.2.1.b Spectrophotometers

A spectrophotometer measures the spectral reflectance or transmission factors of the object. The reflectance spectrophotometer emits a beam of light from a standard light source that strikes the sample. Light is then reflected to the photocell which functions as the detector[64]. It compares the light leaving the object with that of the incident light at each wavelength, thus quantifying any changes in the color. The main components of spectrophotometers are a source for optical radiation i.e. a light source, an optical system for defining the geometric conditions of measurement, some means of dispersing light and a detector and signal processing system that converts light into signals suitable for analysis.

Most of the spectrophotometers used today are not continuous-measuring spectrophotometers. They are the so-called abridged spectrophotometers. They are able to measure only the reflectance factors for certain wave lengths. Continuous recording spectrophotometers for color measurement are used mostly in research laboratories. Most of these instruments are quite large and the samples have to be taken to instrument site for measurement. Recently, portable instruments have been introduced for the ease in color measurements of small samples.

The spectrophotometer measures the spectral distribution (reflectance or transmittance) of an object rather than the three colors. This method is more precise and can determine colors under various illuminants. The data obtained from the spectrophotometer can be plotted to establish spectral reflectance curves or converted to color coordinates for any color space[69].

Recently, computers assisted color measurements are used. A computer can be a part of the spectrophotometer or freestanding. The computer is used in the calibration of the spectrophotometer. In addition, it can calculate the tristimulus values for more than one illuminant-observer condition. Further more, they are able to calculate color difference often with more than one color difference formula. The software is of primary importance for the most productive use of such computerized colorimetric system.

For measurements of small color differences, tristimulus colorimeters are used because of their benefits of high speed and low cost. The uncertainty of tristimulus colorimeters is limited, due to the mismatch of the illumination to that of the CIE illuminants and of the spectral response of the detectors to the CIE color matching functions. Thus they are not suitable for absolute color measurements over a wide range of colors. A number of recommendations on spectral reflectance and color measurements are available from the American Society for Testing and Materials (ASTM) to standardize colorimetric evaluation.

1.2.2.2 Light source

Light source is a very important factor during colorimetric evaluation. The CIE distinguishes between *illuminants,* which are defined in terms of spectral power distribution, and *sources*, which are defined as physically realizable producers of radiant power. The following illuminants are recommended by CIE in colorimetry.

CIE standard illuminant A – The tungsten lamp is a very convenient standard illuminant, because the spectral power distribution of its light is almost entirely dependent on just one variable, the temperature of its filament. The distribution temperature and its color temperature is 2856 K.

CIE standard illuminant B(1931) – has a correlated color temperature of about 4874 K and was intended to represent sunlight. This is now obsolete.

Standard illuminant C (1931) – has a correlated color temperature of about 6774 K and was intended to represent average daylight.

Standard illuminants D (1963) – CIE recommended a standard illuminant D_{65} to represent average daylight throughout the visible spectrum and into the ultraviolet region as far as 300 nm. This illuminant has a correlated color temperature of about 6504 K and is one of the series of D illuminants. The other D illuminants are D_{50}, D_{55} and D_{75} and they posses different correlated color temperatures. The standard illuminant D_{65} is commonly used in color measurements in dentistry.

1.2.2.3 Reliability of instruments

Precision and accuracy are very important during colorimetric evaluation. By precision, it is meant as the consistency with which these color measurements can be made. Accuracy denotes the degree to which color measurements agree with those made by a standard instrument or procedure in which all possible errors are minimized. Precision is affected by random errors. The most common sources of random errors in photo-electric colorimeters, spectroradiometers, and spectrophotometers are variations in sensitivity and sample presentation. Accuracy is affected by systematic errors. Common sources of systematic errors in modern instruments are wavelength calibration, detector linearity, geometry of illumination and viewing, and polarization. These errors may be associated with stray light, wavelength scale, bandwidth, reference-white calibration, thermochromism and fluorescence.

The accuracy of instruments distinguishes between the short-term reproducibility, the long-term reproducibility, and the absolute accuracy. The short-term reproducibility of an instrument is important if color differences are being measured. While testing the short-term accuracy of reproducibility, the color difference should not be larger than 0.05-0.1.

The absolute accuracy of a color measuring instrument is by far not as good as its reproducibility. The examination of it is possible only with calibrated standards. Examination of the absolute accuracy of instrument is also made in standardization committees before setting standards. Also companies that have several color measurement systems compare the results of the different systems. From these evaluations it is known that even instruments of the same type can still show color differences. The amount of difference depends on the kind of sample. If we compare instruments of different types, we see that variation increases. Since the accuracy of the measurements is important, the calculated results should not be printed with too many decimal places. It is usual to print the reflectance factors (in percent), the tristimulus values, the coordinates a*, b* and L* as well as the color difference to two decimal places.

1.2.2.4 Calibration

Calibration of the color measuring instrument is important, because the results of these measurements are, to a high degree, dependent on careful and regular calibrations. White standards produced from ceramics, glass or fluorinated plastics, such as halon are used today. The calibration to be done actually depends on the instrument. It has to be done in accordance with the requirements of the manufacturer of the instrument. Uncertainties also arise from the characteristics of the spectrophotometers. Effects contributing to the uncertainty include wavelength error, detector nonlinearity, stray light, bandwidth, and the geometrical conditions for both illumination and viewing.

The effect of bandwidth can be important. For example, bandwidths of 20nm can cause errors of as much as two to three CIELAB units. In order to verify the stated measurement uncertainties for spectrophotometers, calibrated color standards are used. These standards are ceramic tiles manufactured by the British Ceramic Research Association (BCRA). A set of twelve BCRA tiles was measured at HCL (Hemmendinger Color Laboratory) in 1977, and a few months later at NBS (National Bureau of Standards). The CIELAB color-difference averaged over the twelve tiles, between HCL and NBS was 0.25 units. When the measurement was conducted for every four months since that time, it was shown that the repeatability of the above measurement proved to be better within 0.15 CIELAB units[70].

1.2.3 Calculation of color difference

The sensation of color can be described with the help of numbers called tristimulus values. If these values are the same for a pair of samples at one matching condition (illuminant-observer) and the pair of samples is non-metameric, both samples will appear the same to any observer under any light source. The search for a color difference equation started after the CIE system was recommended in 1931. The distance between two samples in a visual uniform color space corresponding to the color difference between the two samples is always called ΔE (Δ is the mathematical symbol for difference). While evaluating color differences, apart from calculating the overall color difference it is essential to look for the individual coordinates as well. These values give valuable information as to the nature of the differences and to what might be done to correct them. The following are the various color difference formulae:

- FMC-2 color difference formula, based on MacAdam ellipses
- NBS color difference formula, based on CIE system
- ANLAB 40 color difference formula
- CIELAB color difference formula, recommended by CIE in 1976

All known formulae had some disadvantages balanced by some advantages. The scattering of the visual judgments was very large; none of the formulas gave equal color difference on the average. In response to worldwide demand, a common language in color had to be found and CIE decided in 1976 to recommend two color spaces for practical use. Starting from these color spaces the CIE recommended two color difference formulas. The formulas are CIELUV and CIELAB.

In practice the CIELAB formula is used more widely. The CIELUV formula is used only in special cases, when additive mixtures are to be judged. The L*, a*, b* (CIELAB) color space and the color difference that result from this color space are described with the following equations;

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

$$\Delta E = [(\Delta L^*)^2 + (\Delta C^*)^2 + (\Delta H^*)^2]^{1/2}$$

Where

L* = lightness

a*, b* = chroma coordinates

C* = chroma

H* = hue

The search for a uniform color space was and is not finished with the recommendation of CIELAB and CIELUV. Today several more modern formulae are used, but none of them is recommended by the CIE to replace CIELAB, but the substitution may be expected in the near future. The best known and the most widely distributed modern formula is the CMC (l:c) formula (Color Measurement Committee, Society of Dyers and Colourists, Great Britain). It is expected that this formula will be recommended by the CIE in the near future[71].

While the color difference ΔE_{ab} is widely used, its chroma scale is known to be fairly nonlinear. For more accurate color difference evaluations, CIE recommended an improved industrial color difference formula in 1994 - CIE94 formula. The color difference ΔE_{94} is calculated from the ΔL, ΔC and ΔH of the CIELAB formula[66].

1.2.3.1 ΔE values and its clinical relevance

The quantification of color differences in dentistry has eliminated ambiguity during shade selection procedures and also in research studies. The threshold for acceptance varied widely among researchers as shown Table 1.1. However, the ADA (American Dental Association) has proposed the CIELAB color system and a limit of ΔE value 2 as the tolerance on shade guides[62, 63, 72]. It can be understood that any color difference ΔE value > 2 is considered to be clinically unacceptable and thus the clinical threshold color difference or clinically acceptable color difference can be agreed to be ΔE value ≤ 2.

Table 1.2 – ΔE values and its clinical relevance in dentistry

Studies	Color differences	Inference
Kuehni FG 1979[73]	$\Delta E = 1$	Detectable by 50% of subjects under controlled conditions
Ruyter IE 1987[74]	$\Delta E > 3.3$	General population can distinguish color difference between the restorations
Johnston and Kao 1989[75]	$\Delta E \geq 3.7$	Poor match
O'Brien, Groh et al. 1990[72]	$\Delta E \leq 2$ $\Delta E < 1$	Clinically acceptable color difference Excellent color match
Ishikawa-Nagai, Sawafuji et al. 1993[76]	$\Delta E \sim 1.5$	Can be visually distinguished
Vichi, Ferrari et al. 2000[31]	$\Delta E < 1$ $\Delta E > 2$	Not appreciable by the human eye Clinically unacceptable
Ragain JC 2000[77]	$\Delta E > 2.75$	Clinically unacceptable
Heydecke, Zhang et al. 2001[78]	$\Delta E \leq 3.7$	Clinically acceptable
Tung, Goldstein et al. 2002[31, 79]	$\Delta E = 1$ to 2	Clinically acceptable
Reich and Hornberger 2002[80]	$\Delta E \sim 1.0$	Average human perception of color changes

CHAPTER 2

2. Research Programme

A successful color match of the restoration to that of the natural teeth is an important aspect of dental restoration demanding esthetic precision. The all-ceramic restoration is considered to be a reliable choice for such esthetic restorations[2]. The color of the all-ceramic crown is influenced by the color of the underlying substructure components might include the post, core, remaining tooth structure and luting agent as well as the ceramic material itself[3]. Several studies have focused on the factors that influence the final color of an all-ceramic crown, such as the type of all-ceramic material, the translucency and its thickness and documented that these factors influences the masking ability of the all-ceramic materials[81, 82].

Core build-up materials are used to reconstruct fractured or broken down teeth and to restore endodontically treated teeth[5]. The use of direct resin based core build-up materials is likely to increase due to the ease of its use. Assessment of the physical and mechanical properties of core materials reported in the literature, revealed that many composite based core materials possess the compressive and tensile strengths similar to that of dental amalgam[39]. Dental composites have been considered as acceptable restorative materials for anterior applications due to its superior esthetics, acceptable clinical performance and the lack of metallic mercury[42]. Composite core's ability to mask the color of underlying post material contributes well to the esthetics of the restoration.

The introduction of the prefabricated post system was well accepted because of its reduced chair time. Prefabricated metal posts were most commonly used based on their favorable physical properties and excellent biocompatibility. Unfortunately their metallic color leads to a grayish discoloration of the restoration. This negatively affected the esthetics of restorations involving the anterior teeth[83]. Consequently, the prefabricated non-metallic post system was developed to counter this esthetic compromise posed by the metal posts. Currently available non-metallic fiber-based posts are essentially composed of fibers of carbon or silica surrounded by a matrix of polymer resin, usually epoxy resin[84]. However, the concern over esthetics remained unresolved, as most of them were either opaque white or black. The color of these posts might negatively influence the esthetics of all-ceramic restorations. Fortunately both the composite core material and the all-ceramic material are considered to possess the ability to mask the effect of these posts on the esthetics of restorations.

To obtain esthetic excellence while using these systems in a clinical setting, it is prudent to have a thorough understanding of the influence of substrate color on the final shade of all-ceramic restorations. Thus the objectives of these in-vitro studies are as follows:

(i) To evaluate the intrinsic color stability of composite core materials.

(ii) To evaluate the translucency of the composite cores and their ability to mask the color of prefabricated posts.

(iii) To evaluate the influence of the color of various post and core systems on the esthetics of all-ceramic restorations.

CHAPTER 3

3. Evaluation of the intrinsic color stability of six composite core build-up materials

3.1 Introduction

Discoloration is a major esthetic failure of direct tooth-colored restorations. Shades of both chemical and light-cured composite resins was reported to change over time due to extrinsic or intrinsic discoloration[46, 85-87]. Extrinsic discoloration may result from surface staining, marginal staining due to microleakage and changes in surface morphology by wear. The intrinsic factors involve the discoloration of the resin material itself, due to the alteration in the resin matrix and at the interface of matrix and fillers[88]. Intrinsic discoloration is material dependent and difficult to be controlled by the practitioner[46].

The need to replace lost tooth structures with materials that best approximate the individual tooth structure both structurally and esthetically led to the development of materials and techniques which are polymer based[39]. It has become evident that these polymer-based direct core materials are being used more commonly than other conventional core build-up materials in recent times[39]. This has led to the concern regarding the color stability of composite core materials. The change in color of the underlying composite core might show through the all-ceramic crown and affect the final esthetics of the restoration. Hence, it is necessary to have a better understanding of its color stability properties to aid in shade selection during restorative procedures. Thus the purpose of this study was to evaluate the intrinsic color changes of six composite core materials over a period of three weeks.

3.2 Materials & Methods

3.2.1 Selection of materials

Six commercially available composite core materials were selected for the study: Bis-Core® Natural, Bisco [BN]; Bis-Core® Opaque, Bisco [BO]; CoreRestore2® White, Kerr [CW]; CoreRestore2® Universal, Kerr [CU]; Core-Flo®, Bisco [BCF]; Ti-Core Natural®, EDS [TC].

3.2.2 Sample fabrication

Five disks of each material were fabricated (10.0 mm diameter and 3.0 mm thickness) using ring shaped Teflon moulds (Fig 3a). The materials were placed in the mould and covered with mylar strips and glass plates on both sides to extrude the excess and to obtain a uniformly smooth surface. The materials were manipulated according to manufacturers' instructions. The dual cure resin materials (BN, BO, CW and CU) were polymerized using Polylux II (KaVo, Germany), light cure units. Light output was measured with a power-intensity meter/radiometer prior to the curing of each group of specimens, to ensure a minimum light output range of 480-500 mW/cm^2. The dual cure resins were cured on both sides for 40 seconds. The fabricated discs were then polished using a water-resistant, No.2400 sand-paper. During sample preparation and measurement the sample surface were kept free from contamination. Each sample was stored at 37ºC and 100% humidity throughout the period of the study.

3.2.3 Evaluation of color stability using a spectrophotometer

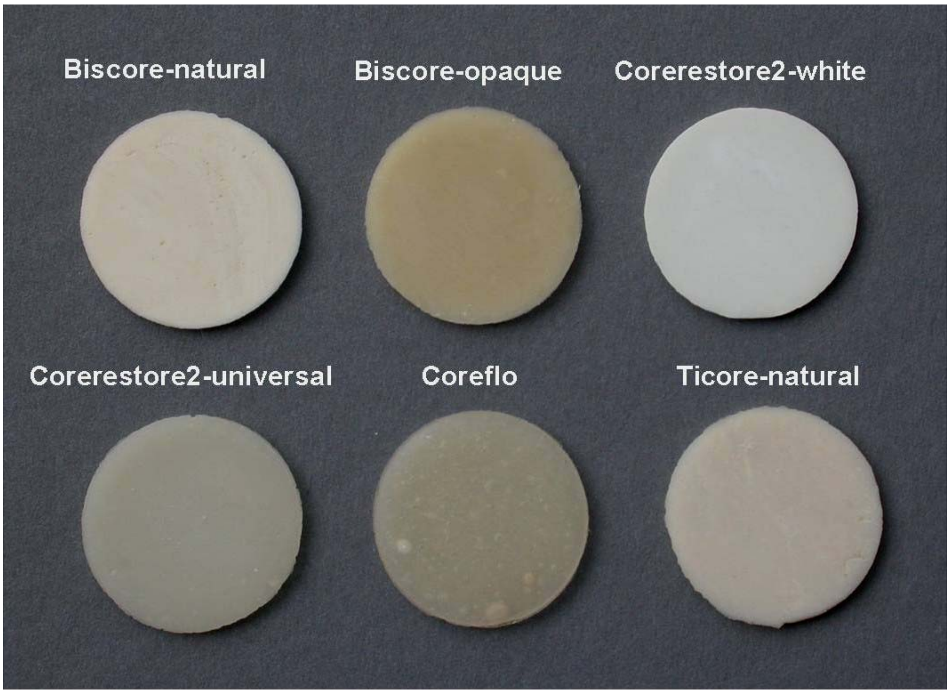
Color measurements were performed using a reflectance spectrophotometer (CM-2600d, Minolta, Japan) with a measuring aperture of 3 mm, D_{65} illumination and 10° observer. Measurements were calculated and analyzed using CIELab color system. The instrument was calibrated prior to measurements. All the specimens were subjected to color measurements immediately after fabrication, then at the end of first, second and third week. The color measurements obtained on day 0 were used as a baseline. L*, a*, b* values were measured and the differences in each color coordinates (ΔL*, Δa*, Δb*) were calculated by obtaining the differences in the individual coordinate parameters between baseline (b) and at each of the various time intervals (i) [($\Delta L^* = L_b^* - L_i^*$); ($\Delta a^* = a_b^* - a_i^*$); ($\Delta b^* = b_b^* - b_i^*$)].

L* is the lightness coordinate, proportional to Value (brightness), its value ranges from zero (perfect black) to 100 (perfect white) and a* and b* are chromaticity coordinates. The a* and b* coordinates designate positions on a red/green and yellow/blue axis respectively (+a = red, -a = green; +b = yellow, -b = blue). The total color difference (ΔE*ab) was calculated using the following formula:

$$\Delta E = \left([L^*_i - L^*_0]^2 + [a^*_i - a^*_0]^2 + [b^*_i - b^*_0]^2 \right)^{1/2}$$

The spectrophotometric data was then analyzed using the repeat measurement technique. Multiple comparisons adjusted with Bonferroni method was used to compare the color changes of composite cores over time.

Figure 3a: Specimen disks of composite core materials



3.3 Results

The mean ΔE values of all composite cores over the period of study are presented in Table 3.1 and Figure 3b. The composite core materials studied exhibited a significant color change over time ($p<0.0001$). The amount of color change differed between the materials, with ΔE values ranging from 1.0 to 3.0 (Table 3.1). Corerestore2-White showed the highest change in color whereas Biscore-Opaque recorded the least compared to the rest of the materials studied (Fig 3b).

It was found that the mean ΔE values of BO was significantly lower than BN, CW, CU and BCF ($p<0.0032$, $p<0.0001$, $p<0.0001$ and $p<0.0001$ respectively) whereas the ΔE values of CW was higher than all the other composite cores studied at a significance level of $p<0.0001$. The ΔE values of composite core were significantly different from each other ($p<0.0001$). A significant increase in ΔE values was observed in the first week and which then relatively stabilized throughout the three week period of observation, with ΔE values less than 0.5 (Fig 3b).

Figures 3c, 3d and 3e present the mean ΔL*, Δa*, Δb* values of the materials tested. All the composite core materials exhibited a decrease in its brightness over time as evidenced by the negative ΔL values obtained (Fig 3c). At the end of the third week BN, CW and BCF showed an increase in a* values indicating the shift toward the red scale, whereas CU and TC shifted towards the green chroma scale (Fig 3d). After three weeks, the colors of CW, CU and TC showed an increase in b* values indicating a shift towards the yellow scale, whereas BN and BO showed decrease in b* values causing the color to shift towards the blue scale (Fig 3e).

Table 3.1: Mean ΔE values and Standard Deviation of composite core materials over a period of three weeks

Composite cores \ Time	1st week	2nd week	3rd week
	Mean ΔE (SD)	Mean ΔE (SD)	Mean ΔE (SD)
Bis-Core natural - BN	1.56 (0.19)	1.65 (0.13)	1.63 (0.11)
Bis-Core opaque - BO	0.78 (0.11)	0.99 (0.19)	0.89 (0.20)
Corerestore2 white - CW	2.99 (0.71)	3.15 (0.71)	3.25 (0.75)
Corerestore2 universal - CU	1.92 (0.15)	2.13 (0.17)	1.73 (0.22)
Core-Flo - BCF	1.85 (0.25)	2.10 (0.30)	1.97 (0.20)
Ti-Core natural - TC	1.11 (0.19)	1.61 (0.39)	1.48 (0.33)

Figure 3b: Intrinsic color changes of six composite core materials over a period of three weeks based on ΔE values

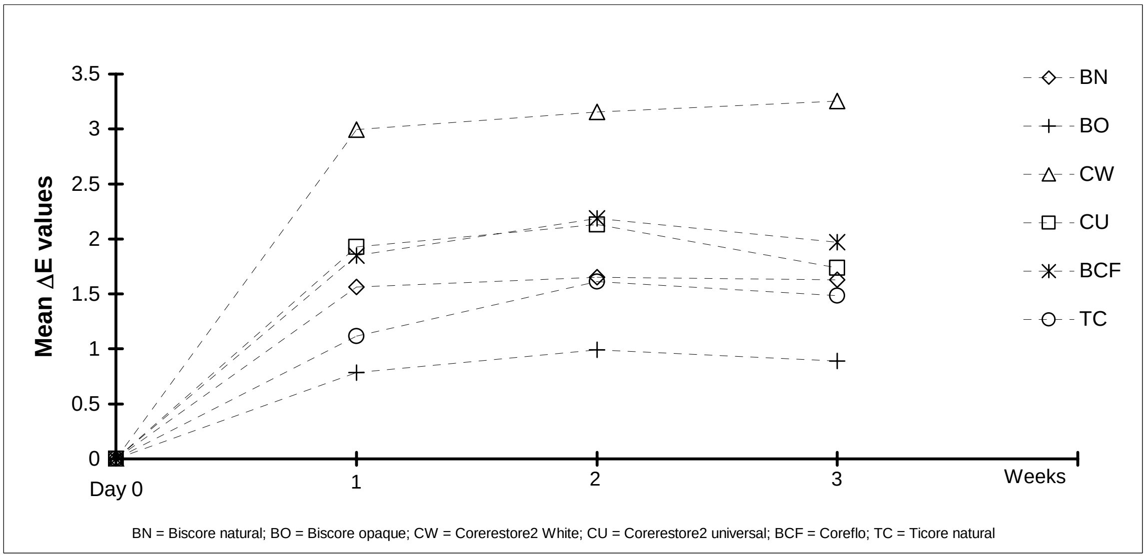


Figure 3c: Mean ΔL values of six composite core materials over a period of three weeks

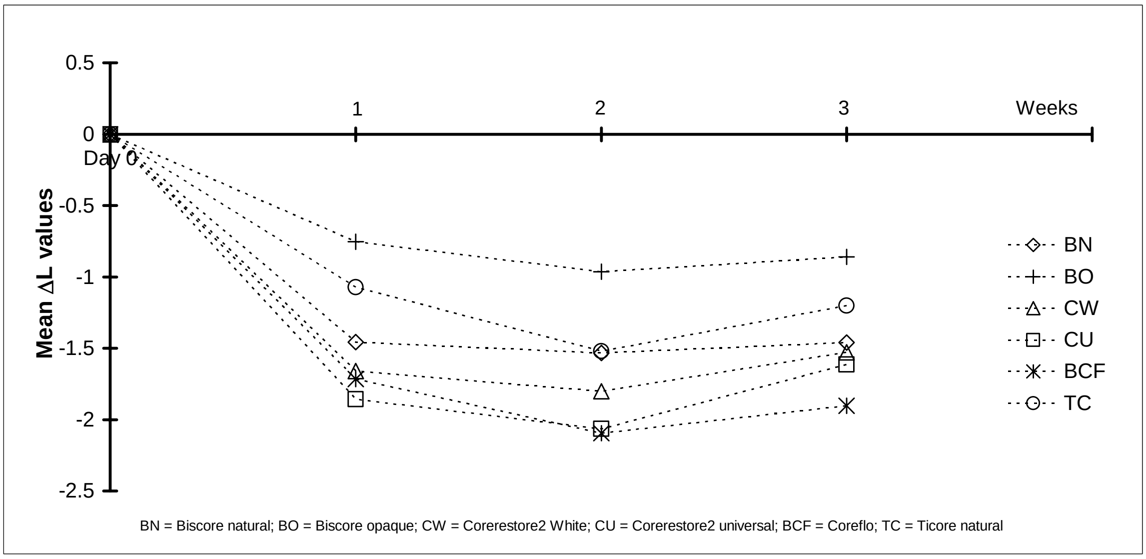


Figure 3d: Mean Δa* values of six composite core materials over a period of three weeks

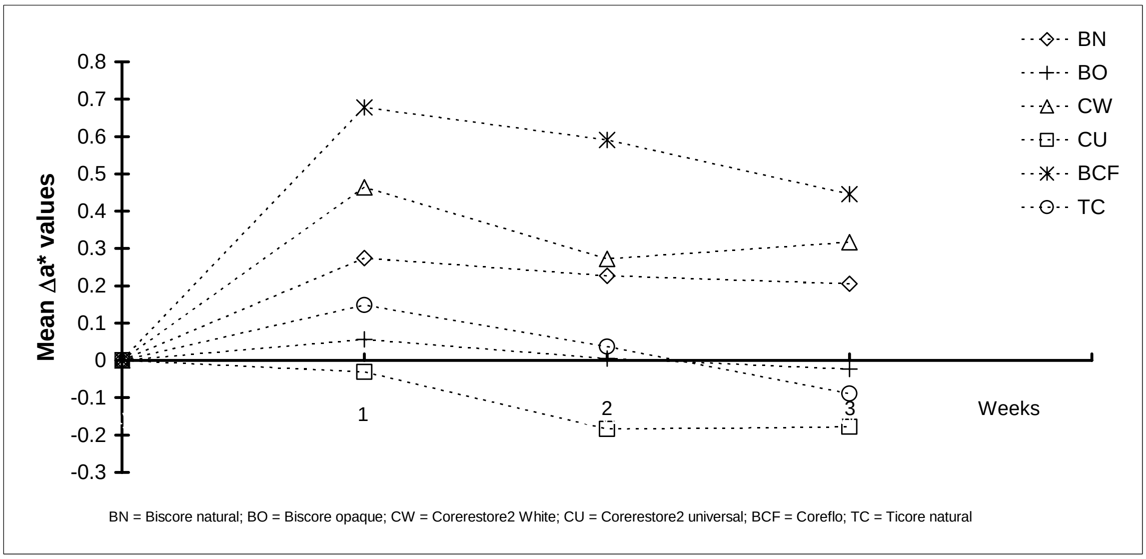
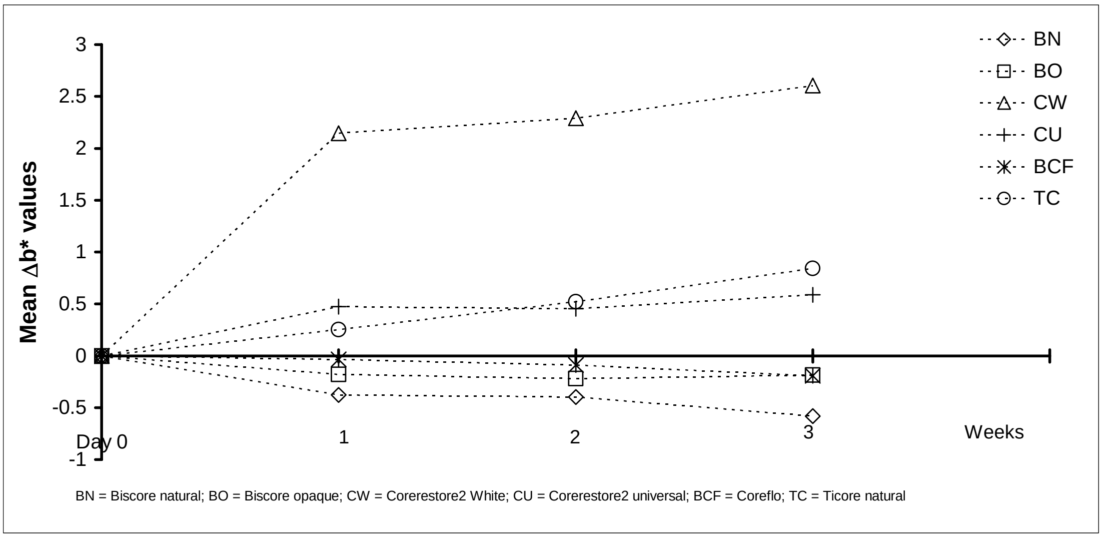


Figure 3e: Mean Δb* values of six composite core materials over a period of three weeks



3.4 Discussion

The success of an esthetic restoration depends on the shade match and its color stability, apart from its structural and functional stability of the restoration. Any perceivable discoloration in the restorations can be disconcerting to the patient and may constitute failure of the restoration[89]. Studies have demonstrated that both chemically and light-cured composite resins can change color over time by either extrinsic or intrinsic discoloration[46, 86, 90, 91]. Several in-vitro studies using accelerated aging techniques have demonstrated intrinsic changes in the color of composite resins over an extended period of time[46, 90, 91]. Unlike these earlier studies, this study was performed without exposing the specimens to accelerated aging conditions, to simulate the normal clinical circumstance.

Due to human's subjective nature of color perception, instrumental colorimetric techniques have been used in the dental field to achieve quantitative evaluation of color difference and as well as to eliminate the subjective interpretation of visual-color comparison. Instruments such as Spectrophotometers and Colorimeters have been frequently used to measure color changes in dental materials[92-94]. Moreover, numeric description or quantification of color change provides a more precise definition of the magnitude of the color differences[85]. Color difference (ΔE) is calculated mathematically, and its value has to be interpreted to correlate with limits of human's visual detection[74]. Unfortunately, the clinically acceptable color difference observed in dentistry varied between researchers. The quantification of the acceptable difference ranges from as low as ΔE value = 1 to as high as 3.7 as shown in Table 1.1 in chapter 1. In 2001 ADA adopted ΔE value < 2 as a guideline for color tolerance[62, 63]. Hence, $\Delta E \leq 2$ was used as the color difference threshold in this study.

Most of the composite cores studied exhibited color change that were within the threshold value ($\Delta E \leq 2$), which are presumed to be clinically acceptable, except for Corerestore2-white which showed ΔE value 3 (Table 3.1). Graph in Figure 3b shows a sharp increase in ΔE value of the composite cores within the first week followed by a relatively minute color change in the second and third week. The color can be considered to stabilize by the end of one week after fabrication. It was also observed that the changes in the L values contributed more to the overall color change of the composite cores than the change in the a* and b* values. All the materials were observed to get darker over time. From clinical perspective, the change in brightness (value) is more readily apparent to the human eye than the differences in chroma[95].

The intrinsic color of composite resin materials changed when the materials were aged under various physical-chemical conditions, such as ultraviolet exposure, thermal changes and humidity, indicating its multifactorial etiology[96]. Studies have shown less internal discoloration in the light cured resin than in the chemically cured materials[86, 87]. It was also reported that dual cured resin were less color stable than light cured resins[89]. In this study, chemically cured composite core did not exhibit a significant color change compared to the dual cured resins. In fact, CW a dual cured resin, showed the highest color change.

Internal discolorations are material-inherent properties that are mainly caused by the initiator system but can also be based on the type of monomer used[97]. It was considered that the amine activator was responsible for internal discoloration in chemically cured and dual cured resin composites[87, 89]. It was also found that discoloration is associated with the type and quantity of amine activator. Besides the amine component, it has been conjectured that the inhibitor, BisGMA and peroxide may also influence the internal discoloration of resin composites[87]. In addition, internal discoloration of the material may also result from deterioration of matrix, fillers and matrix-filler interface as well as the oxidation of unreacted pendant methacrylate groups in the resin matrix[87].

The internal discoloration among light cured resins can be due to the presence of unreacted molecules or polymerized resins, resulting in undesirable mechanical properties and has the susceptibility for discoloration[89]. One of the major constituent of a photocuring dental material is the photoinitator, camphorquinone[97]. It is a yellow chemical because of its very strong absorption band at 468nm[97]. Though used in small quantity, approximately 0.03-0.1% (m/m, mass-percent), it significantly influences the color of the material[98]. During irradiation or light curing, it changes its color from yellow to almost colorless. Therefore, it is characteristic of a material containing camphorquinone as a photoinitator that it is significantly more yellow prior to irradiation than afterwards. If curing is insufficient the materials still retain a certain degree of yellow. Under the influence of ambient light a further conversion of camphorquinone occurs although the resin is already polymerized. This effect, which is described as ‘bleaching’ can only be avoided by a proper curing process[97].

The other important components of photoinitator systems are tertiary aromatic or aliphatic amines, which act as so-called synergists or accelerators[97]. The aliphatic amines are more color-stable than the aromatic amines[99]. All amines are known to form byproducts during the photoreaction, which tend to cause yellow to brown discolorations under the influence of light or heat. These discolorations depend on the type and the amount of synergist added to the photoinitator system.

Endogenous discolorations, which are mainly caused by the respective photoinitator system, are irreversible, unlike the exogenous discoloration. Therefore, the photoinitator system may not only influence the curing characteristics and the strength of the materials but also have an impact on the color stability[97]. The internal color changes may be due to the type of light curing device used, the curing time and conditions chosen[97].

Though there was a change in color, ΔE values obtained demonstrated that the color change may not greatly affect the esthetics of the restoration when used under all-ceramic restorations. Except for CW which had ΔE value > 2, the color changes for rest of the composite cores were well within the threshold level, which could be considered as clinically acceptable. Moreover, the color change is even less observant with the masking of the all-ceramic crowns. However, under relatively translucent or thin ceramic restoration, the color change of composite core build-up materials should be taken into consideration, especially when esthetics is critical.

Thus the selection of core material should be based on both functional and color stability, as this will aid in achieving an esthetically superior restoration. Future studies could include the analysis of the type of light curing units on the color stability of composite resin materials and the influence of color change of composite core material on the aesthetic appearance of the dental ceramics.

3.5 Conclusions

Based on this short term observation the following can be concluded:

1. All the composite cores studied, with the exception of CW showed intrinsic color change over time with $\Delta E \leq 2$.
2. Biscore-Opaque showed the least color change, whereas Corerestore2-White showed the highest color change compared to the rest of the composite cores studied.
3. There was a significant color change within the first week followed by relative stabilization in the subsequent weeks for most of the materials tested.
4. Except for CW, the intrinsic color change of the composite cores observed was clinically acceptable and should not negatively influence the esthetics of the final restoration.

CHAPTER 4

4. Evaluation of the ability of composite core build-up materials to mask the color of three different prefabricated post materials

4.1 Introduction

The primary objective of the post and core build-up is to replace the missing coronal tooth structure sufficiently, so as to provide the required retention and resistance form for the final restoration[36]. The post endodontic restoration of teeth presents the dental practitioner with the daunting task of selecting the appropriate material from a wide range of materials, techniques and designs[36]. Owing to the patients growing concerns, the selection of materials is now influenced by its mechanical properties, minimal invasiveness, biocompatibility and the esthetic compatibility of both the post and core[36].

Torbjorner et al, reported that prefabricated posts were preferred over cast metal posts, because the failure rate of cast post is twice that of prefabricated metal posts[100]. Though the prefabricated metal post possessed better mechanical properties, it still caused an esthetic concern due its gray metallic color. The development of non-metallic prefabricated posts with improved mechanical properties gave the practitioner more choices. However, the opaque white and black post might still have to be masked. Reports in the literature suggest that this can be partially done if the coronal portion of the post is covered with a tooth-colored composite core material[44]. The ability and appropriate thickness of composite core to mask the undesired post color has not been widely studied. Thus the objective of this study was to evaluate the translucency of composite core materials and also to evaluate its ability to mask the color of prefabricated posts at different thicknesses.

4.2 Materials & Methods

4.2.1 Selection of materials

For this study six commercially available composite core materials, Bis-Core® Natural, Bisco [BN]; Bis-Core® Opaque, Bisco [BO]; CoreRestore2® White, Kerr [CW]; CoreRestore2® Universal, Kerr [CU]; Core-Flo®, Bisco [BCF]; Ti-Core-Natural®, EDS [TC]and three types of prefabricated posts, Aesthetipost (Bisco); C-post (Bisco); Parapost plus (Whaledent) were selected for the study.

4.2.2 Sample preparation

Five disks of each material were fabricated according to the manufacturers' instructions into different thicknesses (0.5 mm, 0.75 mm, 1.0 mm and 5.0 mm thick and 10 mm in diameter) using moulds (Fig 4a). The 5.0 mm thick specimen was chosen as the control based on our pilot study, showing that the shade of the composite cores was not influenced by the background color, when its thickness was at least 5.0 mm.

The composite core materials were placed in the mould and covered with transparent plastic strips and glass plates to extrude the excess and to obtain a uniformly smooth specimen surface. The dual cure resin materials (BN, BO, CW and CU) were polymerized using a light cure unit, Polylux II (KaVo, Germany). Light output was measured with a power-intensity meter or radiometer prior to curing each group of specimens to ensure a minimum light output range of 480-500mW/cm^2. The dual cure resins were cured on both sides of the specimen for 40 seconds. The fabricated discs were then polished by finishing it with a water-resistant, No.2400 sand paper. During sample preparation and measurement the sample surface were kept free from contamination. The specimens were then stored in 37ºC and 100% humidity for three weeks before the evaluation to minimize the effect of intrinsic color change (section 3.1).

Disks of Aesthetipost and C-post were fabricated by assembling several posts adjacent to each other with cyanoacrylate embedded in acrylic base. The assembled posts were then shaped into a flat surface with sand paper disc and were 2mm thick and 10mm in diameter (Fig 4b). Parapost was fabricated by machining and shaping a block of Titanium-alloy into a disk of similar thickness and diameter as the other two specimens (Fig 4b). This was done because both the color and material of the Titanium alloy block and the Parapost were similar and it was easier to obtain a flat surface disk using this method for this category.

4.2.3 Contrast ratio

The quantitative translucency values were obtained by comparing reflectance of light when the specimens were placed over a white and black standard background (Fig 4c). The light reflectance for each specimen was measured using a reflectance spectrophotometer (CM-2600d, Minolta, Japan) with a measuring aperture of 3mm, D65 illumination and 10 degree observer. The instrument was calibrated prior to measurements. To obtain the value of translucency for each of the specimens, the contrast ratio (C_R) was calculated using the following formula:

$$C_R = Y_b / Y_w$$

Where Y_w is the Y-value of the specimen backed by a white background, and Y_b is the Y-value of the specimen backed by a black background. The contrast ratio of 1.0 indicates that the specimen is completely impermeable to light and 0 indicates that it is completely permeable to light. General linear model was used to evaluate the effects of composite cores and its thickness on contrast ratio, as well as the interaction between the contrast ratio and the thickness of the composite cores. Multiple comparisons adjusted with Bonferroni method was used to compare the contrast ratio among the various composite core materials.

4.2.4 Evaluation of the masking ability of composite cores

Composite core disks of 5 mm thickness were used as controls. This thickness was chosen as the control based on our pilot study, which demonstrated that the shade of the composite core was not influenced by the background color, when the thickness was at least 5 mm. Color of these respective composite control disks were measured using a spectrophotometer (CM2600d, Minolta, Japan). For the test groups, each composite core disk was placed over the post disk and the color was measured using a Spectrophotometer(CM-2600d, Minolta, Japan) for all the possible combinations as shown in Fig 4d ([6 composite core] x [3 thickness] x [3 posts] = 54 combinations). The color measurements were obtained using CIELab color system, under the standard light source D_{65} and 10° observer with 3mm aperture diameter of the measuring port. Glycerin was used between the core and post disks to eliminate the air medium which might affect the reflectance readings. The instrument was calibrated prior to measurements. The ability of the composite core to mask underlying post was evaluated by calculating the color difference between the control and the test groups. The difference in the values of color co-ordinates (ΔL^*, Δa^*, Δb^*) were calculated as follows: $\Delta L^* = L_c^* - L_s^*$, $\Delta a^* = a_c^* - a_s^*$, $\Delta b^* = b_c^* - b_s^*$ where $_c$ is the control group and $_s$ is the specimen or the test group. The color difference ΔE^*ab between control and various test combinations measurements were calculated using the following formula: $\Delta E = ([L^*_c - L^*_s]^2 + [a^*_c - a^*_s]^2 + [b^*_c - b^*_s]^2)^{1/2}$. General linear model was used to evaluate the effects of types of prefabricated posts, composite cores and the thickness of composite cores, as well as all the 2-way interactions between these factors. Multiple comparisons adjusted with Bonferroni method was used to analyze the effects among the composite core, its thickness and the different types of prefabricated posts.

Figure 4a: Specimen disks of composite core materials

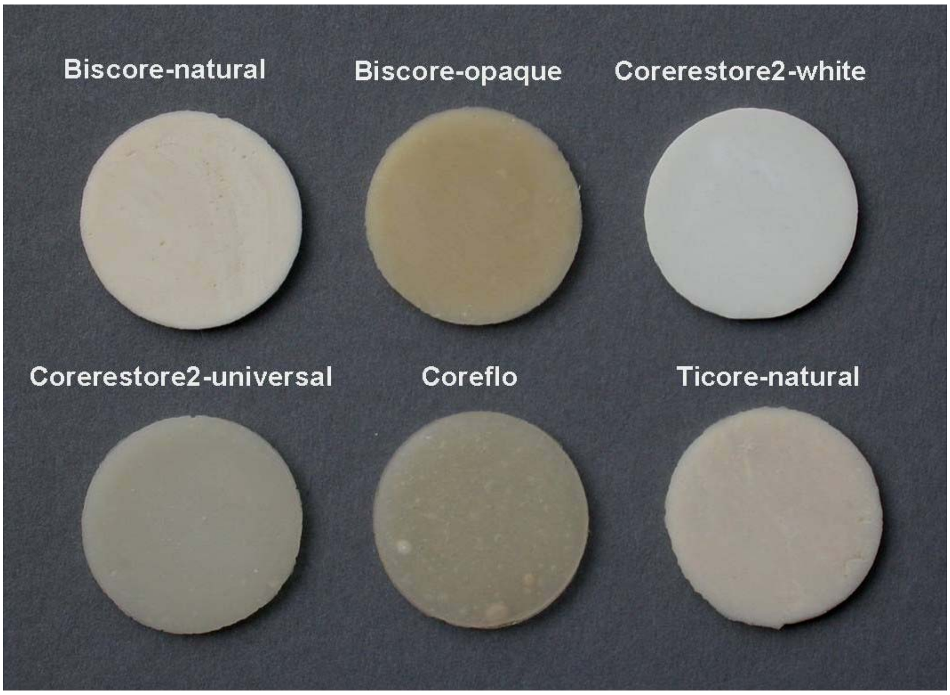


Figure 4b: Specimen disks of prefabricated posts

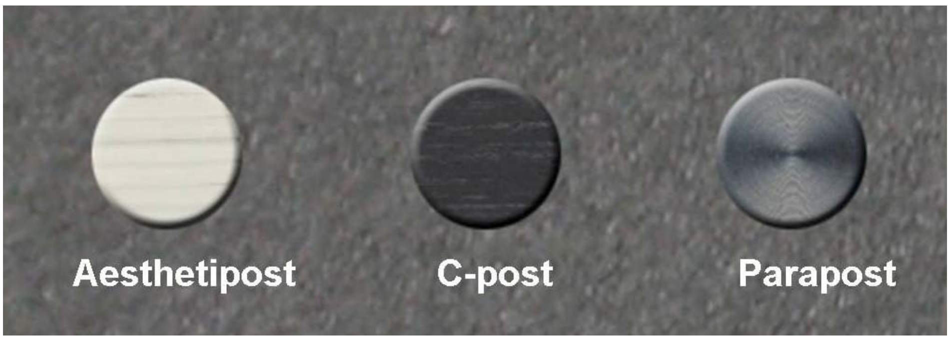


Figure 4c: Measurement set up for the evaluation of translucency of composite core materials by measuring its contrast ratio

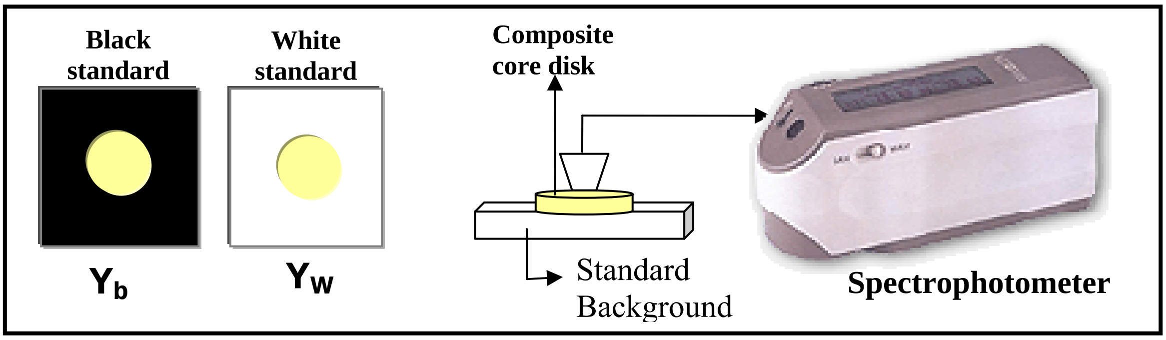
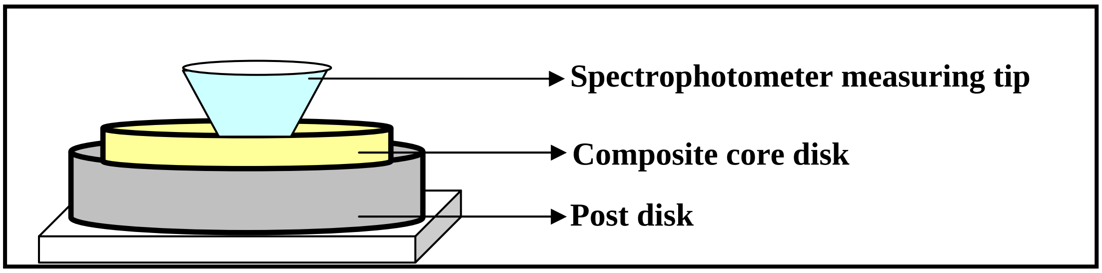


Figure 4d: Measurement set up for the evaluation of composite cores to mask the color of prefabricated posts.



4.3 Results

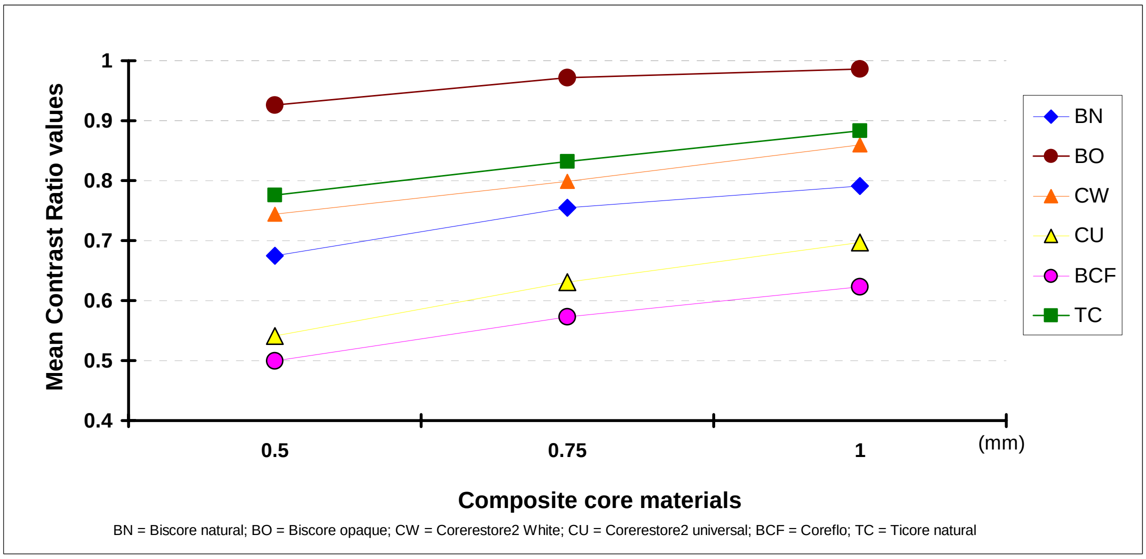
4.3.1 Contrast ratio

The influence of the type and thickness of the composite cores on contrast ratio were significant ($p<0.0001$ & $p<0.0001$ respectively). Moreover, the interaction between the type of material and the thickness was also found to be significant ($p<0.0001$). The mean contrast ratio values and standard deviation of composite cores are summarized in Table 4.1. The mean contrast ratio of the composite cores are in the following order, BO > TC > CW > BN > CU > BCF. The contrast ratio values of the composite cores studied ranged from 0.5 – 0.9. The contrast ratio values of composite cores increased with the increase in its thickness (Fig 4e). BO exhibited significantly higher contrast ratio compared to other materials ($p<0.0001$), whereas BCF exhibited the lowest ($p<0.0001$). When the thickness of the cores increased from 0.5mm to 1.0mm, the translucency decreased by 15% for BN, 6% for BO, 13% for CW, 22% for CU, 20% for BCF and 12% for TC. This clearly shows that, for an equal change in the thickness of the various composite cores, there is a difference in the degree of change in its translucency.

Table 4.1: Mean Contrast Ratios and Standard Deviations (SD) for six composite core materials of varying thickness

Thickness / Composite Cores	0.5mm	0.75mm	1.0mm
	Mean (SD)	Mean (SD)	Mean (SD)
Biscore Natural - BN	0.67 (0.01)	0.75 (0.02)	0.79 (0.03)
Biscore Opaque - BO	0.93 (0.01)	0.97 (0.01)	0.99 (0.01)
Corerestore2 White - CW	0.74 (0.03)	0.80 (0.03)	0.86 (0.01)
Corerestore2 Universal - CU	0.54 (0.01)	0.63 (0.01)	0.70 (0.01)
CoreFlo - BCF	0.50 (0.01)	0.57 (0.01)	0.62 (0.02)
TiCore Natural - TC	0.78 (0.02)	0.83 (0.01)	0.88 (0.01)

Figure 4e: Relationship between Contrast Ratios and thickness of six composite core materials



4.3.2 The ability of Composite cores to mask the color of prefabricated posts

The data from this experiment revealed that the effect of prefabricated posts, the type of composite core and the thickness of composite core were significant on the ΔE value ($p<0.0001$, $p<0.0001$, $p<0.0001$ respectively). All the 2-way interactions between these three factors were significant at a significance level of 0.001. Multiple comparison showed that the masking ability of the six composite cores were different from each other at a significance level of $p<0.0001$ with BO exhibiting the best masking ability, while BCF was ranked as the core with the least masking ability among the materials studied (Table 4.2). The thickness of the composite cores influenced its masking ability at a significance level of $p<0.0001$ (1.0mm > 0.75mm > 0.5mm).

The effect induced by the three different prefabricated posts were significantly different from each other (Parapost > Aesthetipost > C-post) as shown in Fig 4f. The ability of composite cores at various thicknesses to mask the color of posts is shown in figures 4g – 4i. Aesthetipost was masked well by BO, CW and TC ($\Delta E \leq 2$) even at 0.5mm thickness (Fig 4g). C-post and Parapost were masked effectively only by BO of 1.0mm ($\Delta E \leq 2$). Comparing the various post and core combinations, ΔE values of the Parapost group was lower than that of C-post (Fig 4f). The result showed that the masking effects of composite cores were greatly influenced by post color. In other words, certain composite cores were able to satisfactorily mask the color of only certain posts. An example to prove this statement would be TC. It masked the color of Aesthetipost but failed to mask the color of C-post and Parapost (Fig 4f). The result of statistical analysis for this section of the study is shown in Table 4.2.

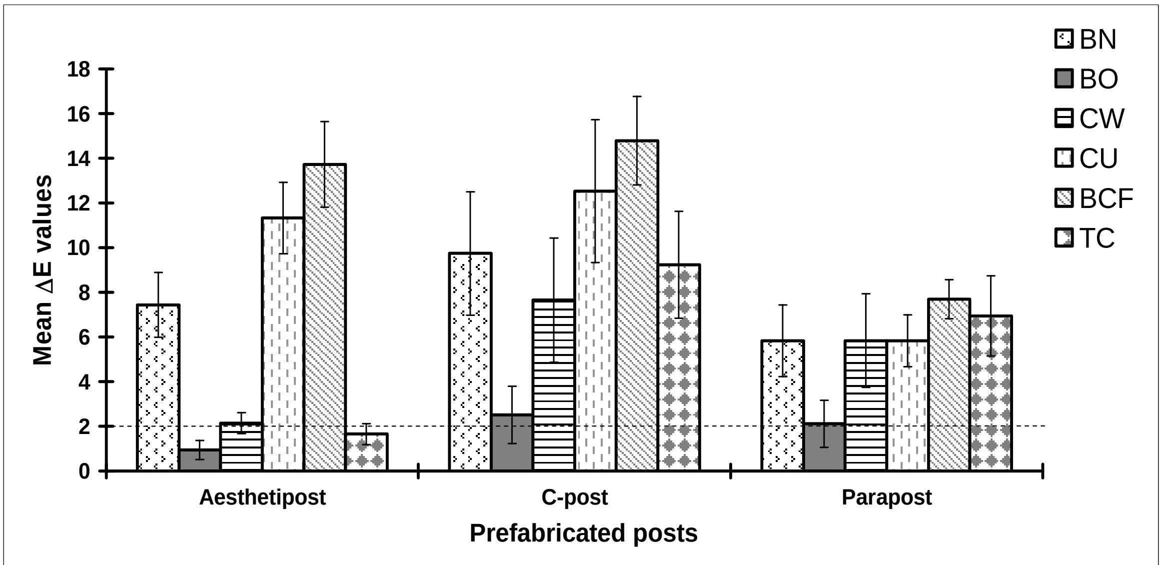
The over all color change was predominantly due to the change in the value or brightness (L^*) of the final shade. Aesthetipost increased the brightness, whereas C-post and Parapost decreased the brightness or value of the final shade. C-post showed more influence on the brightness when compared to that of Parapost (Fig 4j).

Table 4.2: The order of preference of composite cores in masking the posts

Prefabricated Posts	Composite Cores
Aesthetipost	BO>CW>TC>BN>CU>BCF
C-post	BO>CW>TC>BN>CU>BCF
Parapost	BO>BN,CW,CU>TC>BCF

BN = Biscore natural; BO = Biscore opaque; CW = Corerestore2 White;
CU = Corerestore2 universal; BCF = Coreflo; TC = Ticore natural.
The symbol > indicates statistical significance of $p<0.05$

Figure 4f: The ability of various composite cores to mask the color of three different prefabricated posts



BN = Biscore natural; BO = Biscore opaque; CW = Corerestore2 White; CU = Corerestore2 universal; BCF = Coreflo; TC = Ticore natural

Figure 4g: The ability of 0.5 mm thick composite cores in masking the color of prefabricated posts

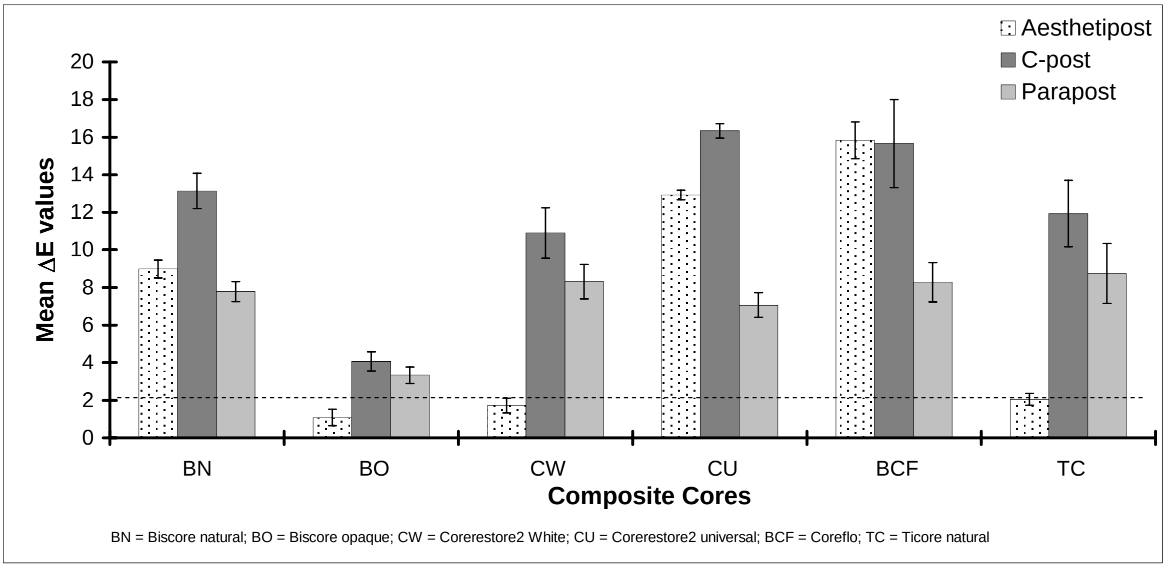


Figure 4h: The ability of 0.75 mm thick composite cores in masking the color of prefabricated posts

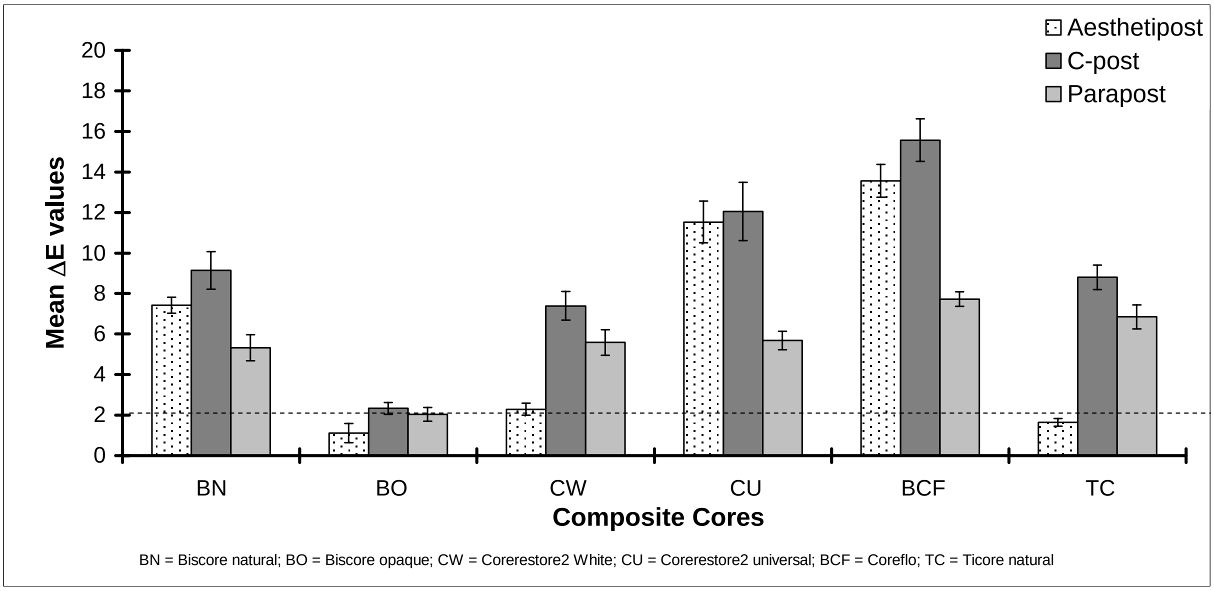


Figure 4i: The ability of 1.0 mm thick composite cores in masking the color of prefabricated posts

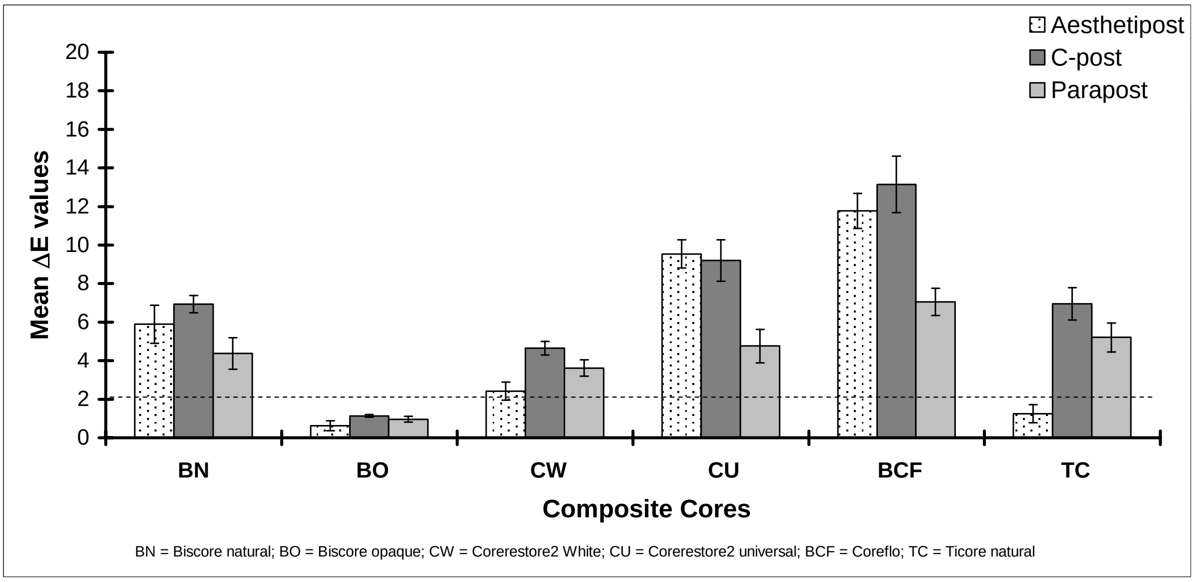
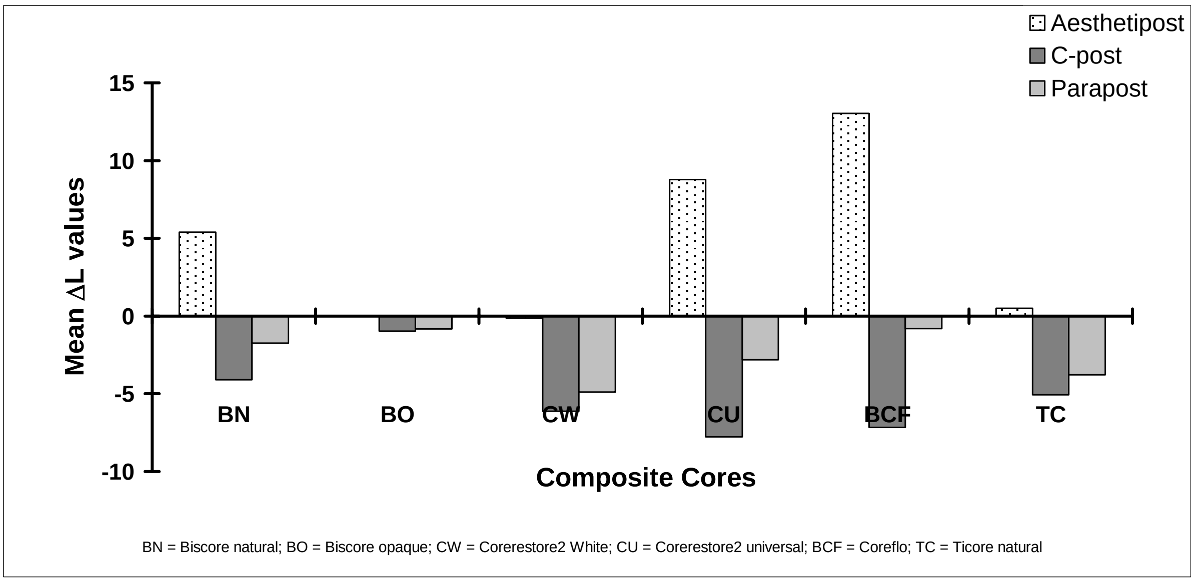


Figure 4j: Influence of the color of prefabricated posts on the brightness of the composite core's color



4.4 Discussion

Prefabricated non-metallic posts were introduced to counter the esthetic drawbacks of metal posts without compromising on its function. Currently available fiber-based posts, like carbon fiber posts are composed of fibers of carbon or silica surrounded by a matrix of polymer resin, usually epoxy resin[84]. Carbon fiber posts are black in color and do not lend themselves to esthetic restorations with all-ceramic units. This lead to the introduction of silica-fiber posts or quartz fiber posts which were considered to be relatively esthetic compared to metal posts and carbon fiber posts[84]. However, posts with carbon fiber core and surrounded with quartz fiber are opaque white and should be masked as well to obtain a predictable final shade for a restoration.

In this study it was observed that Aesthetipost which is opaque white in color increased the brightness of the restoration, whereas C-post (opaque black) and Parapost (metallic) exhibited a decrease in the brightness, resulting in a darker restoration. However, the effect of the color of C-post was more pronounced than that of Parapost and Aesthetipost. Parapost resulted in least color influence on the shade of the restoration. Vichi et.al., reported that while planning an all-ceramic restoration of 1.5 mm thickness, it prudent to consider the color of the substrate, as it might negatively influence the esthetics of the restoration[31].

The ability of the composite core to minimize the influence of the color of prefabricated post can be related to composite cores' translucent property. Contrast ratio is the parameter commonly used to measure the translucency of the materials. It is the ratio of the reflectance of a specimen disks when backed by a black standard to that when backed by a white standard of known reflectance[101, 102]. Evaluation of this optical property of the composite core build-up materials has thus enabled us to predict its color masking ability when used with prefabricated posts during all-ceramic restorations.

The translucency of composite materials is affected by factors such as the particle size and content of the fillers, the refractive indexes of fillers and matrix and the pigments they contain[4]. The increase in the refractive index difference between the fillers and matrix increases the opacity of the materials, due to multiple reflection and refraction at the matrix particle interfaces. Among the six composite core materials, BCF had the lowest contrast ratio (highest translucency) and BO had the highest contrast ratio (lowest translucency). BO, the most opaque resin was able to mask the color of all posts when it was at least 1.0mm thick. The rest of the composite cores were not able to mask the underlying post color even at 1.0 mm thickness. Hence, the clinicians should be aware that the post might influence the color of the all-ceramic crown if the ceramic is not thick enough. Composite core showed selective masking ability depending on the color of the post. BO, CW and TC masked the color of Aesthetipost effectively, on the other hand, CW and TC was unable to mask the color of both C-post and Parapost. CW and TC, due to its inherent color and translucency was only able to mask white colored post and not the black colored post. Increase in the thickness of the composite core improved its ability to mask the color of the prefabricated posts. When used with all-ceramic restorations, composite cores will certainly play a pivotal role in minimizing or eliminating the influence of the color of prefabricated posts.

It was interesting to note that the mean ΔE values increased with the increase in thickness of CW when used with Aesthetipost, and not with other posts (Fig 4i – 4g). This was probably due to the opaque white color of the control specimen of CW which is quite similar to opaque white color of the Aesthetipost. When a thin CW disk was placed over the Aesthetipost, the color of the Aesthetipost had an additive effect on CW resulting in high L values, equaling to the color of the control specimen. The thicker the CW disk, the lesser the effect of the Aesthetipost, hence ΔE values increased with the increase in its thickness to 1.0 mm. This pattern will however change when the thickness of CW nears its control specimen thickness. Whereas when CW was used with C-post and Parapost, the dark color of the posts countered the white color of CW, resulting in a decrease in ΔE values with an increase in its thickness as expected (Fig 4i – 4g). As the results from this work showed that most of the combinations of composite cores were unable to mask the post color, a further study was undertaken with composite cores and all-ceramics to mask the underlying post color (chapter 5).

Based on the results of this study, it can be inferred that the type and thickness of composite cores as well as the type of prefabricated post have a high influence on the color of an all-ceramic restoration. Therefore, it is necessary to consider the type of composite core and prefabricated post to obtain esthetic and functional excellence in post-endodontic restorations.

4.5 Conclusions

Within the limitations of the study the following can be concluded:

1. Biscore – Opaque, exhibited the least translucency, whereas CoreFlo had the highest translucency property among the various composite cores.
2. Increase in the thickness of the composite core materials improves the masking effect. However, most composite cores were not able to mask the underlying post color even at 1.0mm thickness, except for BO.
3. The masking ability of composite core differed with the color of the prefabricated posts. BO, CW and TC masked the color of Aesthetipost satisfactorily, whereas only BO was able to mask C-post and Parapost effectively.
4. The color of posts greatly influenced the final color of the restoration. Parapost showed the least ΔE value, whereas C-post exhibited the highest.

CHAPTER 5

5. Evaluation of the influence of the color of various post and core systems on the esthetics of three all-ceramic crown materials of different thickness.

5.1 Introduction

Ceramics have been advocated as the material of choice for matching the human dentition[13]. The application of all-ceramic systems in restorative procedures allows the near reproduction of the natural appearance of dentition. It is also reported that, recently metal free crowns have become a common practice in providing esthetic restorations[4, 103]. All-ceramic prostheses offer an esthetic advantage over porcelain fused to metal crowns which have high light reflectivity because of the opaque porcelain layered to mask the metal substrate[104]. In the anterior region, all-ceramic crowns have been preferred over metal-ceramic crown restorations because of its esthetic superiority[2].

Often as a result of biomechanical reasons, an endodontically treated abutment tooth must be reinforced by a post and core system[83, 84]. Subsequent to the endodontic treatment a permanent coronal restoration is said to improve the prognosis of the treated tooth[7-9]. When all-ceramic crowns are indicated to provide more esthetic coronal restorations after endodontic procedures, it is essential for clinicians to understand the effect of the abutment color and select an appropriate post and core material that will allow the near reproduction of shade of the natural teeth that is replaced[4]. Since all-ceramic materials are translucent, the color of the restoration can be negatively affected by the color of its underlying substructures. This is certainly an esthetic compromise which most patients might not accept[36].

Though prefabricated metal posts offered some advantages over cast posts, it caused a significant esthetic concern when used under all-ceramic crowns due to “shine through” and unfortunately their metallic color also leads to a grayish discoloration of the root and consequently the gingiva. This may be an enormous esthetic disadvantage in the anterior teeth[83].

The alternative to the cast posts and prefabricated metal posts are the prefabricated non-metallic posts system that offers both functional and esthetic benefits over the latter [105]. One of the first viable non metallic prefabricated post was the carbon fiber post (C-post, Bisco) made from unidirectional pretensed carbon fibers in an epoxy matrix[56]. Though it did not corrode like metal and offered exceptional functional benefits it possessed a black color and did not provide any significant esthetic advantages over prefabricated metal post[56].

Later, improved versions of the carbon fiber post were introduced with a white quartz sheath surrounding a black carbon fiber core (Aesthetipost, Bisco). Though the white coating on the post would effectively eliminate the shine-through of metallic post and unaesthetic black color of C-post, most of the light transmission through the root and gingival complex was still diminished[56]. These white opaque posts might negatively influence the esthetics if used under thin all-ceramic restorations by increasing the brightness of the restoration. The recent introduction of quartz-fiber posts which are relatively translucent and more tooth colored is said to offer an esthetic advantage over the rest[84].

These bright white or black opaque colored posts posed an esthetic concern as it might affect the final shade of the restoration, especially when the ceramic thickness is less than ideal. Vichi et al (2000) suggested that when the space for the ceramic decreases to 1.5mm or less, there is a need to consider the substrate color as they might negatively influence the esthetics of an all-ceramic restoration. This study thus evaluated the ability of varying thickness of all-ceramic restorations to mask the post color, when used in combination with 1.0 mm thickness of composite core materials.

5.2 Materials & Methods

5.2.1 Selection of materials

For this experiment six commercially available composite core materials, Bis-Core® (Natural), Bisco [BN]; Bis-Core® (Opaque), Bisco [BO], CoreRestore2® (White), Kerr [CW]; CoreRestore2® (Universal), Kerr [CU]; Core-Flo®, Bisco [BCF]; Ti-Core Natural®, EDS [TC], three types of prefabricated posts, Aesthetipost, Bisco; C-post, Bisco; Parapost plus, Whaledent and three all-ceramic systems; Empress 2 (Ivoclar, Leichtenstein); Finesse (Dentsply); Procera (Nobel Biocare) of shade A2 were selected for the study.

5.2.2 Sample preparation

Samples of Aesthetipost and C-post were fabricated by assembling several posts adjacent to each other using cyanoacrylate embedded in acrylic base. The disks were then shaped and polished with a sand paper disc to achieve a smooth flat surface (Fig 5a). The Parapost sample disk was fabricated by milling a Titanium-alloy into a disk of 2 mm thickness. All the post specimen disks had a uniform diameter of 10 mm (Fig 5a).

Five composite core disks of 10 mm diameter and 1.0 mm thickness were fabricated for each of the six materials selected for this study (Fig 5b). The thickness of 1.0 mm was chosen because it was shown in the previous chapter that most of the composite core even up to 1.0 mm failed to mask the underlying post. The pilot study also showed that the combination of ceramic with core thickness less than 1.0 mm were not able to mask underlying post color. Specimens were fabricated by pressing the material into the mould covered with mylar strips and glass plates to obtain a uniformly smooth specimen. Composite disk of 5 mm in thickness and 10 mm in diameter for each material were also fabricated and it served as the control, when placed under the corresponding all-ceramic disk. All composite core build-up materials were manipulated according to manufacturers' instructions. The specimens were then stored in 37ºC and 100% humidity for 3 weeks before the evaluation to minimize the effect of intrinsic color changes from influencing the ΔE values (Chapter 3).

Since, restorations fabricated with different brands of porcelain have noticeable color difference despite having the same nominal shade[81], three types of all-ceramic material of the same shade were chosen for the present study. Five ceramic disks of 10mm diameter and three different thicknesses (1.0, 1.2 and 1.5 mm) were fabricated for each all-ceramic system selected for this study (Fig 5c). Empress 2, Finesse and Procera cores were fabricated (0.7 mm thick) and then layering were done to make up for the desired thickness. The materials were manipulated as per manufacturers' instruction.

5.2.3 Evaluation of substrate color influence

5.2.3.1 Evaluation of translucent property of all-ceramic materials

The translucency of all-ceramic materials was first evaluated by using a spectrophotometer. All-ceramic disks of each system (1.0mm thick and 10mm in diameter) were placed, against white and black backgrounds and the light reflectance for each specimen were measured using a reflectance spectrophotometer (CM-2600d, Minolta, Japan) with a measuring aperture of 3mm, D_{65} illumination and 10° observer. Measurements were performed using color analysis software (Spectra-magic version 3.1, Minolta, Japan). The instrument was calibrated prior to measurements. The translucency values for the specimens, the contrast ratio (C_R) were obtained using the following formula:

$$C_R = Y_b / Y_w$$

Where Y_w is the Y-value of the specimen backed by a white background, and Y_b is the Y-value of the specimen backed by a black background. The contrast ratio of 1.0 refers to complete impermeability to light and 0 refers to total permeability to light. The contrast ratio values were then statistically evaluated using One-way ANOVA and multiple comparisons adjusted with Bonferroni method was performed.

5.2.3.1 Influence of prefabricated post color on esthetics of all-ceramic materials

The color of ceramic disks (3 types x 3 thickness) stacked on composite core disk of 5 mm thickness (6 types) were measured and served as controls. The test groups consisted of posts (3 types), composite cores (6 types) and ceramic disk (3 types x 3 thickness) stacked over each other for all the combinations with ceramic disk facing the color measurement tip of the spectrophotometer (Fig 5d). Glycerin was used between the all-ceramic, composite core and post specimen disks to eliminate the air medium which might affect the reflectance readings. For each combination the color measurements or CIE L*, a*, b* values were measured according to CIELab color scale relative to the standard light source D65 and 10° observer on a spectrophotometer with an aperture diameter of 3 mm. The instrument was calibrated prior to measurements. Color measurements obtained from each test groups were then compared with their respective control groups. This gives the influence of post color on the color of the all-ceramic crowns with composite cores.

The influence was quantified by calculating the color difference between the control and the test combinations. The differences (ΔL^*, Δa^*, Δb^*) were calculated as follows: $\Delta L^* = L_c^* - L_t^*$, $\Delta a^* = a_c^* - a_t^*$, $\Delta b^* = b_c^* - b_t^*$ where $_c$ is the control and $_t$ is the test combination. The overall color difference (ΔE^*ab) were obtained using the following formula: $\Delta E = ([L^*_c - L^*_t]^2 + [a^*_c - a^*_t]^2 + [b^*_c - b^*_t]^2)^{1/2}$. General linear model was used to evaluate the effects of different types of post materials, composite cores, ceramic materials and its thickness on ΔE^*ab values, as well as all the 2-way interactions between all these factors, and multiple comparisons adjusted with Bonferroni method were performed.

Figure 5a: Specimen disks of prefabricated posts

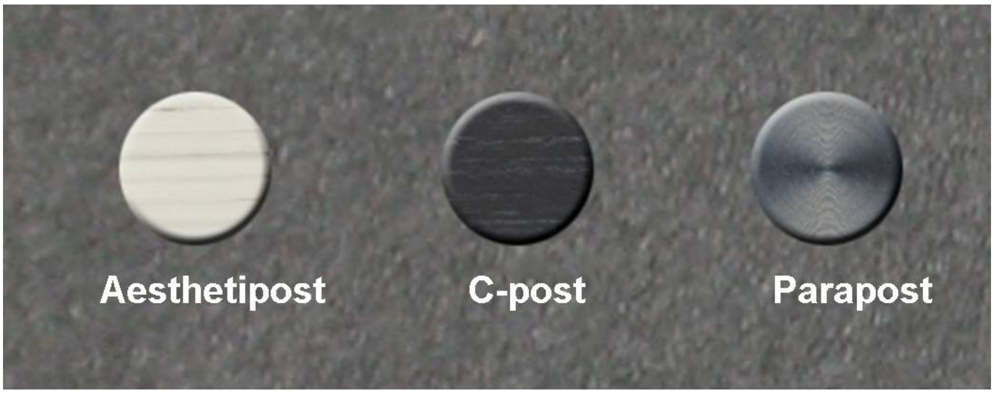


Figure 5b: Specimen disks of composite core materials

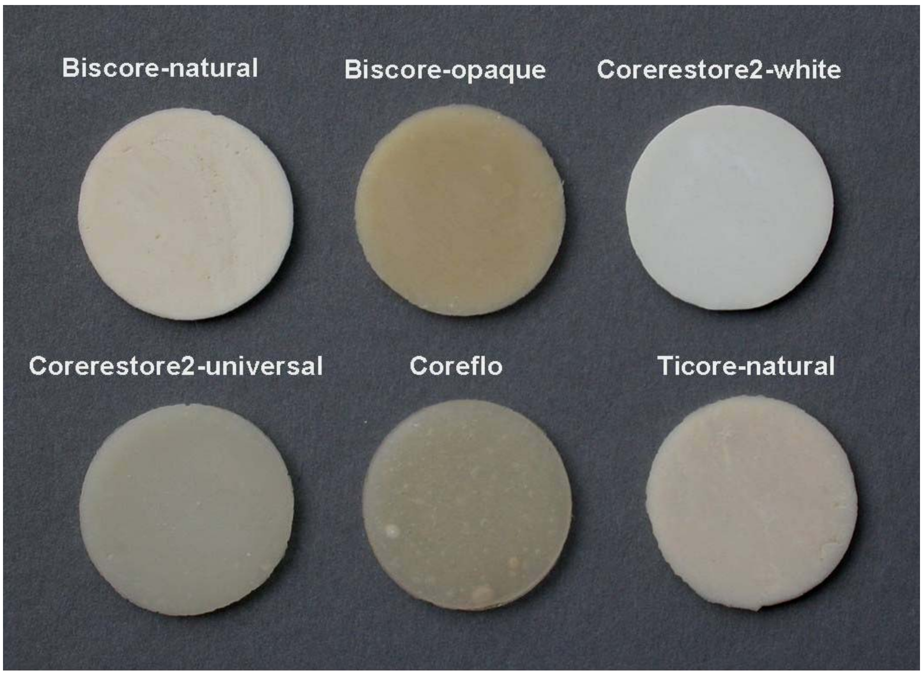


Figure 5c: Specimen disks of all-ceramic materials (shade A2)

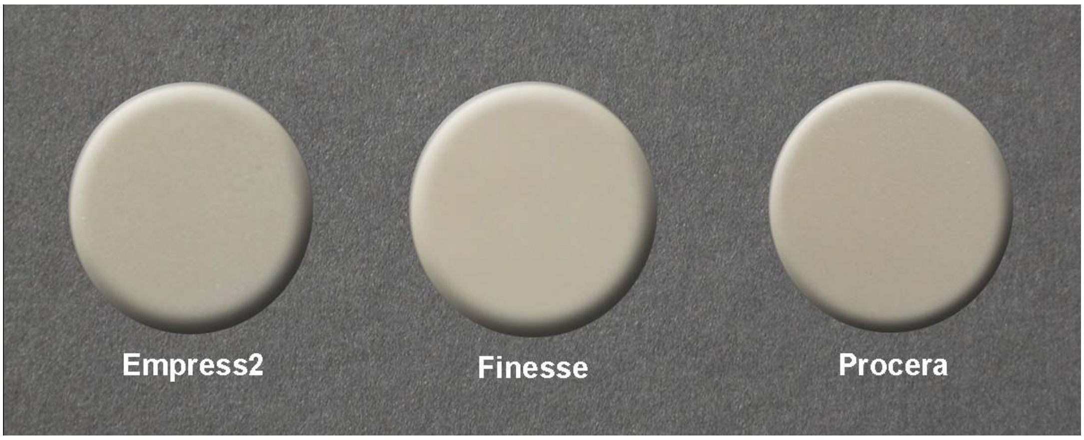
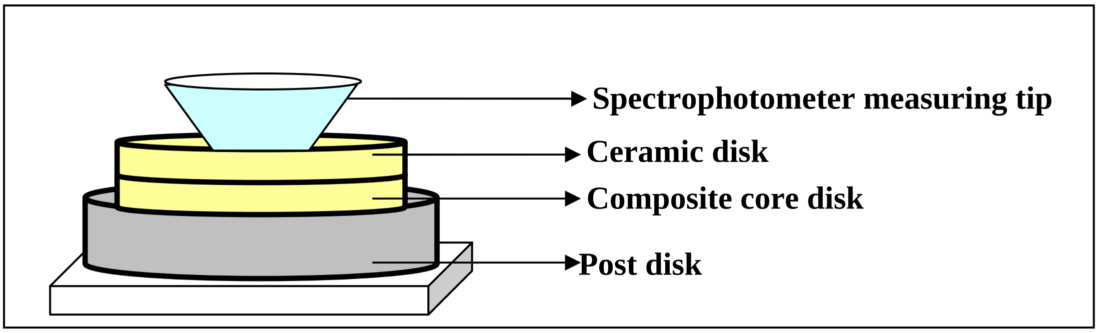


Figure 5d: The measurement set up for evaluation of the influence of the color of posts and cores on the esthetics of all-ceramic restoration

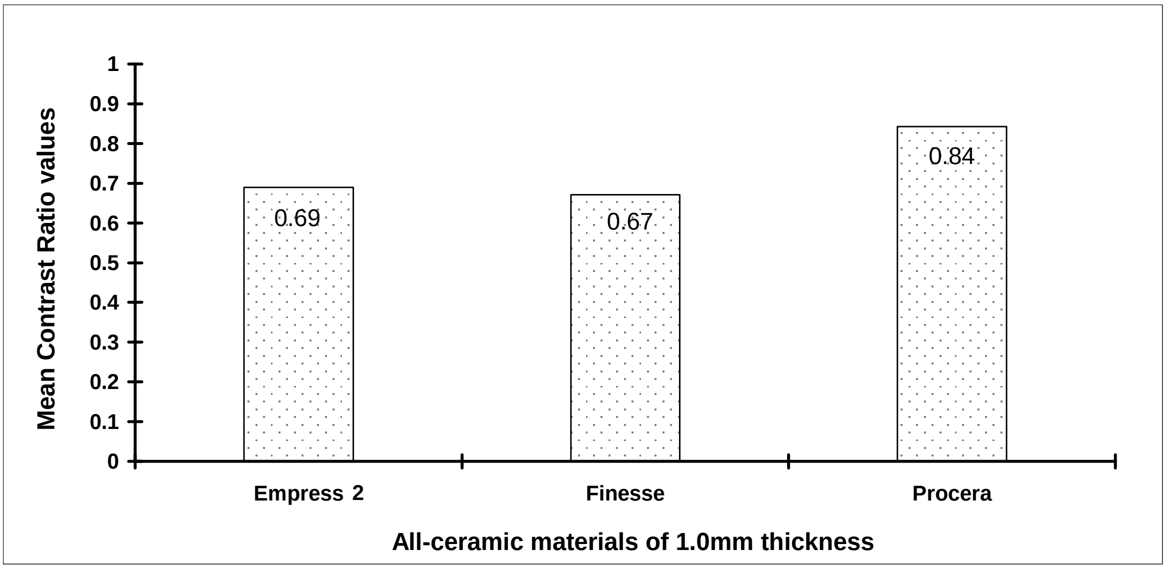


5.3 Results

5.3.1 Translucent property of all-ceramic materials

The influence of the type of ceramic on the contrast ratio was different from each other at significance level of $p<0.0001$. The contrast ratio of Procera (0.84) was found to be significantly greater than other ceramics (Fig 5e). It was found that there was a significant difference in the contrast ratio values between Empress 2 and Finesse (0.69 and 0.67 respectively) but it is also shown that the degree of translucency of these two materials was found to be similar at a thickness of 1mm.

Figure 5e: Mean Contrast Ratio of three types of all-ceramic materials



5.3.2 Influence of prefabricated post color on esthetics of all-ceramic materials

Figures 5f – 5k indicate the mean ΔE values for all the combinations of post, core and ceramics. Statistical analysis revealed that the effects of different types of posts, composite cores, all-ceramic types and its thickness on the final shade was found to be significant at $p<0.0001$ and all the 2-way interactions between these factors were also significant ($p<0.0001$). The influences of different types of posts on the final shade was found to be significantly different from each other ($p<0.0001$). The influence of type of all-ceramic materials was also found to be significantly different ($p<0.0001$) with Procera exhibiting the best potential to mask the influence followed by Empress 2 and Finesse. The thickness of the all-ceramic material had a significant influence on the final shade of the all-ceramic material ($p<0.0001$) with 1.5 mm thickness showing the least to be influenced by post color followed by 1.2 mm and 1.0 mm.

Based on the results, it can be inferred that the influence of the post's color on the all-ceramic materials can be minimized by the use of composite core under ceramic restoration. Statistic analysis revealed a significant difference ($p<0.0001$) among different types of composite cores. The mean ΔE values of BO and CW groups were less than 2 in all three thicknesses of ceramics. It can be concluded that the combination of BO or CW with at least 1.0 mm ceramic successfully masked the color of all the post tested in this study. There was no significant difference between Biscore-natural and Ticore-natural and between Coreflo and Corerestore 2-universal.

Influence of the color of Aesthetipost:

For Aesthetipost, all the ceramic disks in three different thicknesses showed ΔE value ≤ 2 when BO, CW or TC was used as the core build up material (Fig 5g, 5h

& 5k). For BN, most of the groups exhibited ΔE value less than 2 except for Finesse and Empress 2 at 1.0 mm thick in which it was only slightly over 2 (2.26 for Finesse and 2.15 for Empress 2) as shown in Fig 5f. When CU was used as the composite core, a minimum thickness of 1.5 mm of all-ceramic was required to obtain ΔE ≤ 2 (Fig 5i). Whereas, when BCF was used as the core material, only Procera of 1.5 mm thickness exhibited ΔE ≤ 2 (Fig 5j).

Influence of the color of C-post:

All the ceramic materials with a thickness of at least 1.0 mm showed ΔE value ≤ 2 when used in combination with BN, BO or CW (Fig 5f, 5g & 5h). All the combinations of Procera were able to mask the color C-post satisfactorily with ΔE values ≤ 2 regardless of the type of composite core and thickness of Procera disk (Fig 5f – 5k).

For Empress 2 and Finesse, a minimum thickness of 1.2 mm of ceramic was required to achieve the color threshold of less than 2 when used with CU (Fig 5i). With BCF as the composite core, a thickness of 1.5 mm of Empress 2 and Finesse was required to result in ΔE values < 2 (Fig 5j). When using TC, it required at least 1.5 mm of Finesse disk was required to satisfactorily mask C-post, while the two other ceramics showed ΔE < 2 in all combination (Fig 5k).

Influence of the color of Parapost

All the ceramics, at all three thicknesses exhibited ΔE values ≤ 2 when Parapost disk was used, irrespective of the type of composite core (1 mm) used (Fig 5f – 5k).

Figure 5f: Influence of post color on the final shade of all-ceramic restorations with Biscore-Natural as the composite core material.

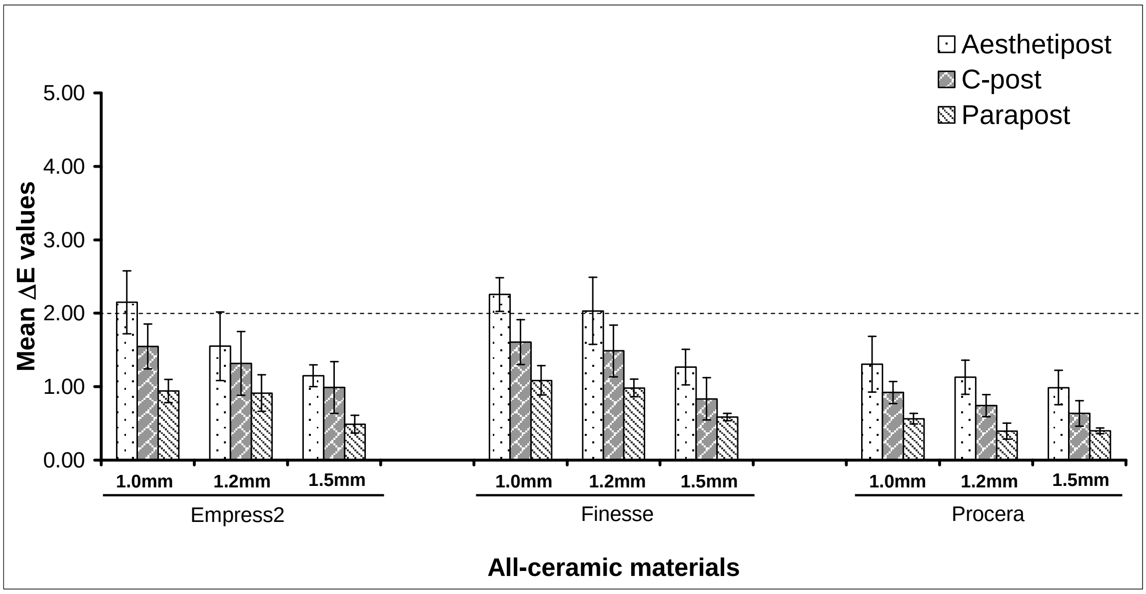


Figure 5g: Influence of post color on the final shade of all-ceramic restorations with Biscore-Opaque as the composite core material.

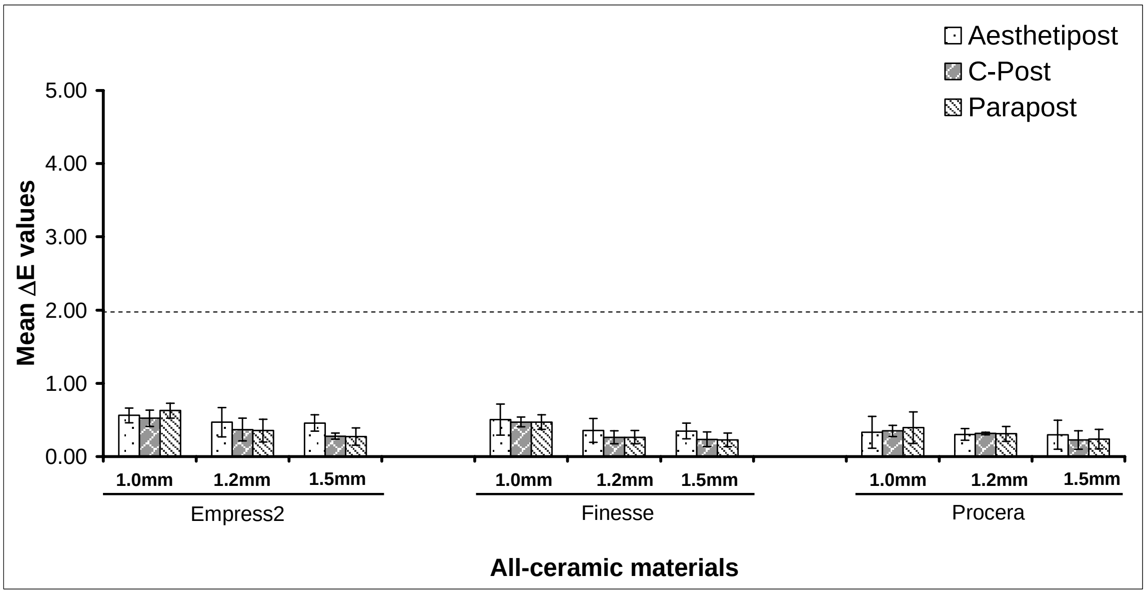


Figure 5h: Influence of post color on the final shade of all-ceramic restorations with Corerestore2-White as the composite core material.

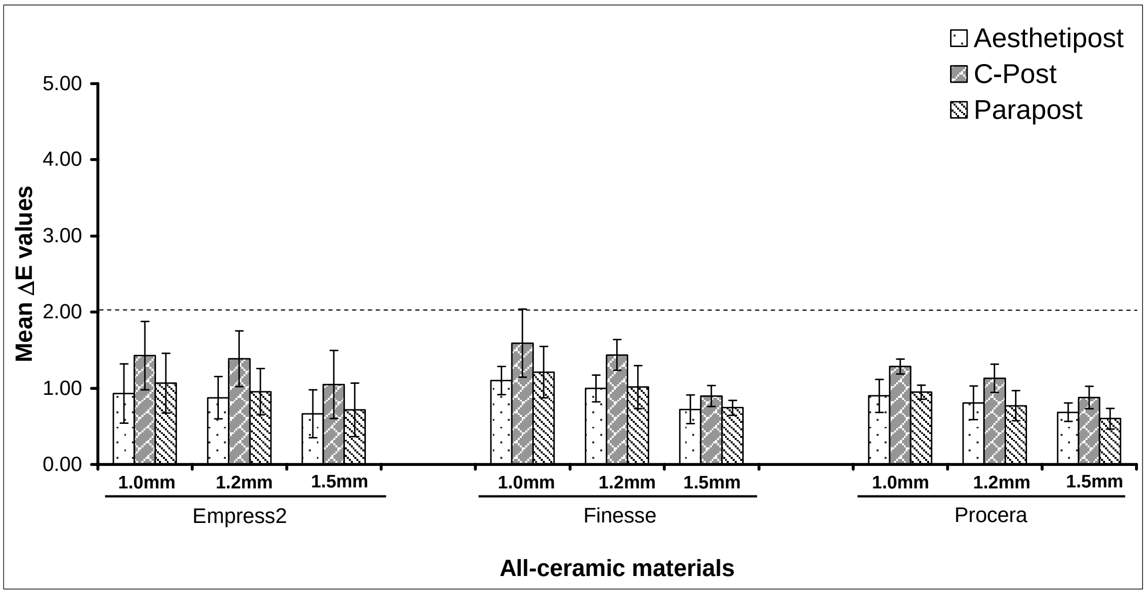


Figure 5i: Influence of post color on the final shade of all-ceramic restorations with Corerestore2-Universal as the composite core material.

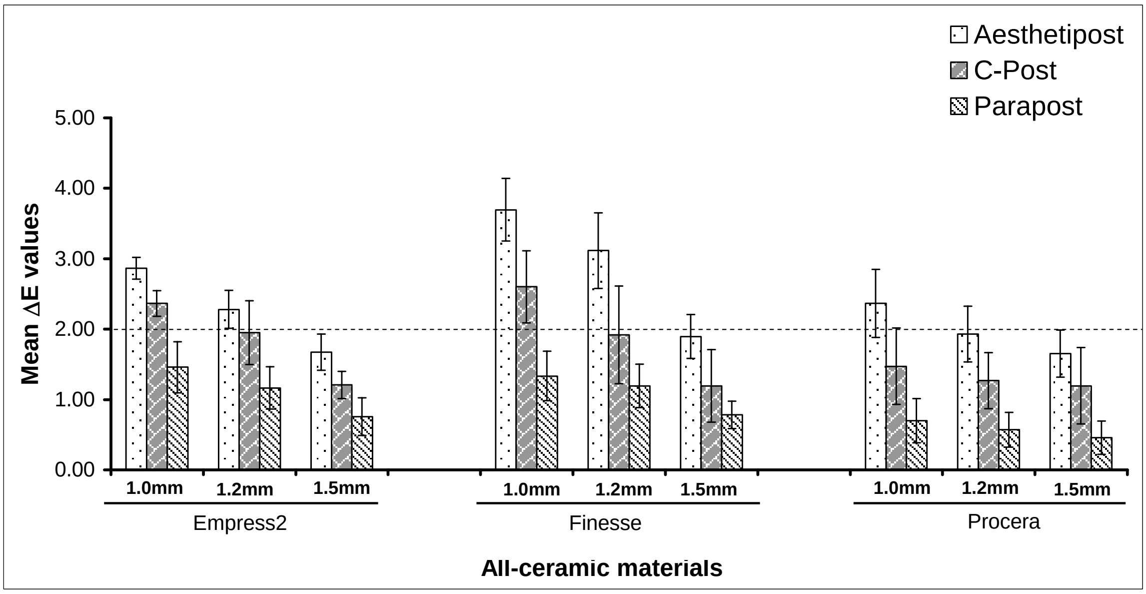


Figure 5j: Influence of post color on the final shade of all-ceramic restorations with Coreflo as the composite core material.

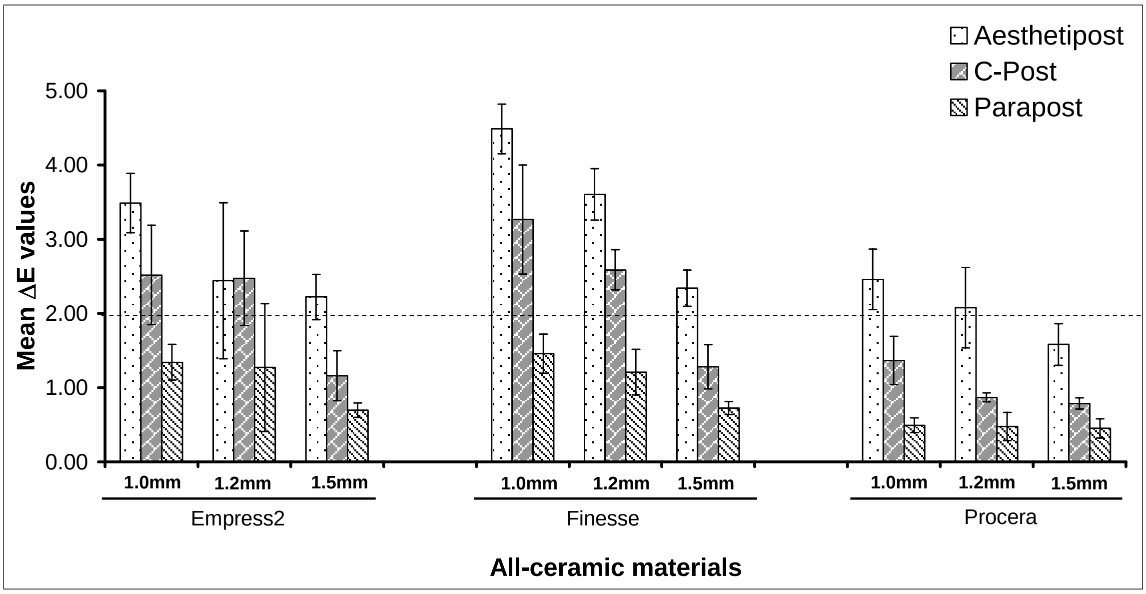
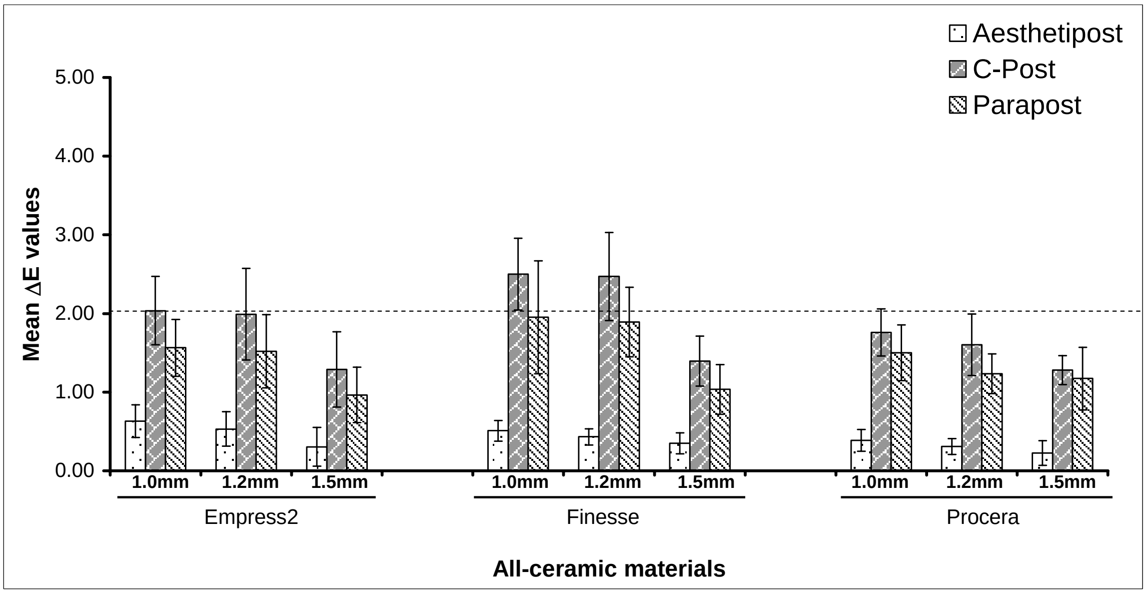


Figure 5k: Influence of post color on the final shade of all-ceramic restorations with Ticore-natural as the composite core material.



5.4 Discussion

The translucent property of all-ceramic materials is said to be important in achieving a more esthetic result. It is also important that the translucency should be adequate to mask the undesired substrate color. All-ceramic crowns having no metal substructure, permit greater light transmission, thereby improving the color and translucency of the restoration[6]. Based on the evaluation of the translucent property of the all-ceramic materials, it can be inferred that Procera has the best potential to mask underlying substructure color followed by Empress 2 and Finesse. It can also be generally agreed that the increase in its thickness will improve its masking ability.

The translucency of dental porcelain is largely dependent on light scattering[30]. If the majority of light passing through a ceramic is intensely scattered and diffusely reflected, the material will appear opaque. If only part of the light is scattered and most of it is diffusely transmitted, the material will appear translucent[106]. The translucency of all-ceramics can be affected by properties such as its thickness[10], its crystalline structure[106], and its core[13]. The amount of light that is absorbed, reflected and transmitted depends on the amount of crystals within the core matrix, their chemical nature, and the size of the particles compared to the incident light wavelength[10]. Variation in translucency may be attributable to differences in crystal volume and the refractive index. Less crystalline content and a refractive index close to that of the matrix cause less scattering of light. For example, Empress 2 has a lower crystal content within the matrix than that of Procera, thus contributing to the differences in their translucency[10]. Increase in crystalline content to achieve greater strength generally results in greater opacity thus influencing the esthetics[13, 28, 107]. Ceramic core translucency is also one of the primary factors in controlling esthetics and should be considered during selection of materials, as the core of the all-ceramic material contributes to the overall color of the restoration as well as the translucency of the ceramics[13, 108]. The thickness of the material significantly affects the color of the porcelain. Therefore, adequate tooth reduction without violating pulpal integrity is encouraged[82]. It is also prudent to take the substrate color into consideration while planning for all-ceramic restorations.

An earlier study has shown that dark colored opaque posts were masked efficiently when the thickness of the all-ceramic restoration exceeded 2 mm[31]. However, the ceramic disks of 1.0 mm and 1.2 mm were also included in this study, as clinicians sometimes face restriction in the cervical regions. The cervical region with minimal ceramic thickness might pose an esthetic concern when colored prefabricated posts are used during restoration. Increase in the thickness of the ceramics improved the esthetics of the restoration by minimizing or eliminating the influence of the color of post material depending on the thickness and the type of the ceramics. Procera exhibited better masking ability even at thickness below 1.5 mm compared to other all-ceramic materials studied.

It is can be inferred from this study that composite core does play a significant role in minimizing the effect of the underlying post color. The earlier part of the study (chapter 4) found a difference in the masking ability of composite core based on its type and thickness. This suggests that appropriate composite core selection will enhance the esthetics of an all-ceramic restoration when an opaque colored prefabricated post is used. The results in this chapter was in agreement with the earlier one (chapter 4) that Biscore-opaque showed higher efficacy in masking the post color than other cores used and the masking ability of the composite core materials is dependent on the post color. The present study reported that the color of Parapost representing metal posts was easier to be masked compared to Aesthetipost and C-post when used in all-ceramic restorations.

Resin luting cements has become the luting agent of choice when compared to zinc phosphate because of its high bond strength to tooth, metal and ceramics, ease in manipulation and has a high predictability[36]. This study did not take luting cement thickness and color into consideration because it was found to have minimal influence[31] and it is only instrumentally detectable and not of clinical significance[31]. The influence of the thickness of the luting cement is also low and the operator has difficulty in controlling its thickness[31].

Disks of these materials were used instead of restored tooth models in this laboratory based study, only to obtain precision during evaluation. Since a flat surface such as that of the discs would enable to obtain a precise colorimetric evaluation than curved surfaces as that of a restored tooth model. This study was restricted to only one shade of all-ceramic material. Future studies can evaluate the masking effectiveness for the other commonly used shades of all-ceramic materials. It would also be prudent to evaluate the effect of composite core color on the final shade of an all-ceramic crown as well. Since, some of the composite cores with its opaque property might affect the color of all-ceramic crown, despite the fact that it masked the underlying post color satisfactorily. Thus, to obtain esthetic success for a post-endodontic restoration of an all-ceramic crown, the selection of an appropriate post, core and all-ceramic system is of utmost importance.

5.5 Conclusions

Within the limitation of this study the following can be inferred:

1. The color of prefabricated posts negatively influences the esthetics of all-ceramic restorations.
2. Parapost exhibited the least influence compared to Aesthetipost and C-post.
3. The influence of post color can be minimized or eliminated when an appropriate type and thickness of composite core material is used.
4. Procera exhibited better masking ability of substructure color followed by Empress 2 and Finesse.
5. When the thickness of the all-ceramic material was below 1.5 mm thickness it is mandatory to take substructure color into consideration and appropriate post and core should be selected to obtain restorations with esthetic precision.

CHAPTER 6

6. General conclusions

All-ceramic systems, composite core build-up materials and prefabricated posts are the major components which would influence the esthetics of dental restorations. The appropriate combination of these components is necessary in achieving esthetic excellence. These in-vitro studies were designed to evaluate the individual influence of these components and also in various combinations to understand their effects on the esthetics of a restoration, leading to a more scientific guideline for selecting the materials, when color is the primary concern.

Intrinsic color stability of the composite cores was the first factor studied. As discussed in chapter 3, composite resins have shown to discolor after polymerization. Color change of these resins were clinically acceptable ($\Delta E \leq 2$) except for CoreRestore 2 –White. Therefore, with CoreRestore2-White, the clinician should be aware of the impact on the color when using a more translucent ceramic.

In the second study, it was noted that when the thickness of the ceramic was less than 2.0 mm, the color of the underlying substrate could be perceived through the restoration. Unfortunately, it is not possible to achieve 2 mm reduction in every case. Furthermore, the recommended reduction for most of the all-ceramic crown is about 1.2 to 1.5 mm. In this study, composite cores proved to be an excellent material to use when the color of the post need to be masked. Even though most of the composite cores at 1.0 mm thick were unable to mask post color, when used under ceramic, most of them succeeded in helping to mask the underlying post color even when the thickness of ceramic was down to 1.0 mm except for CoreFlow and Corerestore2-Universal

All posts tested have shown color influence up to some extent on the all-ceramics. Surprisingly, Parapost was found to be the easiest color to be masked whereas C-post, as expected, was the most difficult.

Procera proved to be less translucent than Empress 2 and Finesse, emphasizing the fact that it has the ability to mask the color of underlying substructure effectively than the other two all-ceramic materials.

Figures 5f to 5k will aid the clinician in selecting an appropriate composite and ceramic as well as the minimum required thickness when such prefabricated post is used.

The thickness of the composite cores and that of the all-ceramic material have a significant influence in masking the color of the prefabricated post material. When the thickness of an all-ceramic material is less than or equal to 1.5mm, it is strongly advised to take substructure color into consideration for better esthetics. It was found that an increase in the composite core and all-ceramic materials' thickness improved its masking ability resulting in a more predictable esthetic result.

The results of this in-vitro study demonstrated the effects of the major components that would influence the esthetics of a restoration without any external factors influencing the results. Evaluating the effectiveness of individual components of a post endodontic restoration is very necessary, as this would enable the clinician to choose the right combinations of all-ceramic material, composite core and post material to obtain a functionally and esthetically superior restoration.

Based on the results of these studies, one can understand the importance of having the knowledge of optical properties of materials which is essential to obtain esthetic precision during restorative procedures. All of the above mentioned findings will certainly aid the clinician in selecting the most ideal materials for post-endodontic all-ceramic restorations.

CHAPTER 7

7. References (Chapter 1-5)

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