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Effect of Different Esthetic Post-Core Materials on Color of Direct-Composite Restorations: A Preliminary Clinical Study

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Background: The purpose of this study was to determine the influence of 2 different esthetic post materials on the final color of direct-composite restorations by using a digital technique under *in vivo* conditions.

Material/Methods: We included 22 pulpless incisor teeth treated with conventionally cemented zirconia (n=11) and polyethylene fiber (n=11) posts in the study. Teeth were restored with a hybrid resin. The color of direct-composite restorations and contralateral control teeth was measured using a digital technique. The Commission Internationale de L'Eclairage, or CIE, L*a*b* and RGB color systems were investigated. Descriptive statistical analysis was performed for the CIE L*a*b* values. Color differences (ΔE) for the average L*, a*, and b* color parameters between every pair of groups were calculated ($P>.05$).

Results: Significant differences were not found in the color difference luminosity (lum), R, G, B, and L* a* b* values between the zircon-rich glass fiber post (Z) and contralateral control teeth (Cz) ($P>.05$) and between the polyethylene fiber post (P) and contralateral control teeth (Cp) ($P>.05$). However, there was a statistically significant difference between the color a* values of the polyethylene fiber post (P) and contralateral control teeth (Cp) ($p<0.05$). Color differences (ΔE) between the zircon-rich glass fiber post (Z) and contralateral control teeth, and the polyethylene fiber post (P) and contralateral teeth were not statistically significant ($P>.05$).

Conclusions: Definitive restorations were equally affected by the 2 materials. Both materials can be used reliably in clinical practice. However, further research that focuses on the effect of intraoral conditions is needed.

MeSH Keywords: **Color • Polyethylene • Zirconium**

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Background

The most common site of dental impact injuries in the developing dentition is the anterior maxillary teeth [1,2]. Such injuries often lead to pulp necrosis and subsequent arrested tooth development. It is generally agreed that successful treatment of a badly broken tooth is achieved with good endodontic treatment of pulp disease, but also due to good crown reconstruction after completion of endodontic treatment [2].

Casting, such as with gold onlay, gold crowns, metal-ceramic crowns, and all-porcelain restorations with cuspal coverage, is used routinely and is an acceptable method for restoring endodontically-treated teeth. Such restorations can provide endodontically-treated teeth with the desired protection; however, they require extensive tooth preparation and can be expensive [3,4].

Direct-composite coronal reconstruction and direct-composite veneers are conservative, esthetic treatment alternatives in a variety of clinical scenarios, such as for teeth with multiple restorations requiring replacement, short teeth, diastemas, and malformed, malpositioned, or darkened teeth [5–8]. If full esthetic restoration is chosen for endodontically-treated teeth, clinicians use tooth-colored material, including ceramic, fiberglass, or polyethylene fiber with a reinforced composite, to build up post cores [9–11].

Esthetic restoration is done with the aim of replicating natural teeth and providing morphological, visual, and biological acceptance [12]. Although rigorous laboratory and laboratory techniques help maintain the restoration form, color matching is a huge problem for the dentist [4,12]. Instrumental methods have been developed to remove uncontrollable variables during the color matching process [13]. Optical electronics and computer technology detect subtle changes in color and make it possible to quickly and objectively determine color [13–16]

For clinicians who practice esthetic restorative dentistry, restorative materials that are reflective of natural tooth vitality are critical to an esthetically pleasing outcome. This physical property associated with tooth vibrancy is termed fluorescence. By their very nature, teeth, and more specifically, dentin, are fluorescent because they emit visible light when exposed to ultraviolet (UV) light. Even though UV light is not visible to the naked eye, its interaction with dentin is important because fluorescence adds to the natural look of a restoration and minimizes the metamerism effect. This concept is well understood in the dental ceramics industry, and agents that cause the restoration to become fluorescent have been incorporated into porcelain powders in recent decades [17].

Composite material behaves differently than ceramics; the former being more transparent by material design and less

reflective. The development of higher-opacity dentin replacement materials has overcome problems associated with low-value areas representative of the restored area of the tooth. Studies by Powers et al. [18] have raised awareness of fluorescence as an important factor in composite resin materials. The increased vibrancy of the restoration being closer to natural tooth structure is an added benefit, in addition to high translucency.

Whether instrumental or visual, the color must be well known and the parameters to be measured must be known for the color to be accurately determined. The Commission Internationale de L'Eclairage (CIE) $L^*a^*b^*$ color space (CIELAB) and color difference formula [19] specifies the location of a color with 3 coordinate values (L^* , a^* , b^*) and places the object in a three-dimensional color space. The L^* coordinate represents the brightness of an object, represented on the y -axis, a^* represents the red (positive x -axis) or green (negative x -axis) chroma, and b^* represents the yellow (positive z -axis) or blue (negative z -axis) chroma. The color difference (ΔE) between 2 objects can then be determined by comparing the differences between the respective coordinate values for each object. The formula [19] used to calculate color differences in this system is $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$, where ΔL^* , Δa^* , and Δb^* are the differences in the color parameters of the 2 specimens measured for comparison. The numeric description of color gives the numerical value of any color difference between objects. These objects, which should have color harmony in the prosthetic dentistry, are shade tab, porcelain and natural.

Digital shadow analysis systems have been introduced to the market to remove the distortion of subjectivity and color communication of visual color analysis and to ensure that the esthetic restorations are made precisely and uniformly by technicians [20–24]. Color differences of up to 2 ΔE units cannot be distinguished by the naked human eye, and color changes in this range are considered clinically tolerable according to the American Dental Association [25]. Furthermore, Yap et al. [26] reported that computerized analysis performed better than the human eye in cases with $\Delta E > 3$. In addition, Bentley et al. [27] performed a computer analysis of digital images using luminosity (L), red, green, and blue (RGB) values, and internal color controls, and reported a reproducible toughness index from image to image. In addition, Çal et al. [28] concluded that color measurements obtained by digital analysis are in accordance with the spectrophotometric evaluations according to their a^* and b^* values. The mechanical and physical properties of endodontically-treated teeth restored with esthetic posts and composite have been investigated [29–32]. In addition, many prospective and retrospective *in vivo* and *in vitro* studies have evaluated the performance of post-core restorations [31,33]. However, no study has evaluated the color matching of these restorations.

Previous studies have limited reliability in terms of clinical practice [34] because, under non-clinical conditions, an intra-oral scenario was performed *in vitro* in an environment that does not mimic color adaptation and evaluation [34]. Only 1 study [16] was conducted to determine tolerances for *in vivo* color perceptibility and acceptability. Therefore, the present study sought to determine the influence of 2 different esthetic post materials on the final color of direct-composite restorations using a digital technique in a preliminary clinical trial.

Material and Methods

Twenty-two pulpless teeth (16 maxillary incisors and 6 mandibular incisors) in 11 patients (5 males and 6 females; age range 18–32 years) treated with conventionally cemented zirconia (n=11) or polyethylene fiber (n=11) posts were studied. Subjects were randomly allocated to the study groups. The post systems consisted of esthetic posts from 2 different manufacturers: a zircon-rich fiberglass post (Snowpost, Lot H 040; Carbotech, Ganges, France), (1.4 mm diameter) and an ultrahigh-molecular-weight polyethylene fiber post (Bondable Reinforcement Ribbon DENSE; Ribbond, Seattle, WA) (2-mm thickness).

Inclusion criteria were clinical and radiographic confirmation of the need for root canal treatment. Teeth were included if at least 50% of residual sound tooth structure was present. Following placement, consecutive patients who were satisfied with esthetics and function who had chosen to not have a crown were selected. Treatment and recall protocols were approved by the Ethics Committee at the University of Dicle, Faculty of Dentistry, Turkey, and patients gave informed consent before enrollment in the clinical evaluation.

The root canal fillings were evaluated radiographically for length, density, and adaptation to the walls of the root canals. All teeth were prepared for post-and-core foundations following established preparation guidelines [11]. These guidelines included posts with a minimal length equal to the lengths of the clinical crowns and asymmetrical groove preparation to avoid rotation of the posts and cores. A ferrule at least 1 mm in height was also prepared consistent with the residual hard tissue, although in some situations this was not possible over the entire circumference. After trial insertion, the root canals were rinsed with H₂O₂ and NaOCl and then dried with paper points (Dentsply Maillefer, Ballaigues, Switzerland). Canals were etched using 35% phosphoric acid (3M ESPE, St. Paul, MN) for 30 s, rinsed with distilled water, and dried thoroughly until no moisture was visible.

The zircon-rich fiberglass posts (Z) were cemented conventionally with a dual-cure resin cement (Panavia F; Kuraray,

Osaka, Japan). Any excess cement was removed and the final restorations were completed using a hybrid resin (Clearfil AP-X; Kuraray, Osaka, Japan) after polymerizing. Resin shade was confirmed according to contralateral teeth shade. Direct-composite coronal reconstruction was performed using an incremental technique. The thickness of composite resin restoration was least 2 mm from the post surface.

The dowel area prepared after the width of the reinforcing polyethylene fiber (P) was determined and was measured twice with a periodontal probe to determine the length of the fiber required. The 2 fibers were then cut with special shears (Ribbond Shears; Ribbond). The fiber pieces were covered with a dual-polymerizing resin composite (Liner Bond II V; Kuraray) and placed in a light-tight container. The internal surfaces of the root canal and pulp chamber were treated with the same system of primer (Liner Bond II V, primer A and B mixture; Kuraray) for 30 s and dried using a light air current for 15 s. A dual-polymerizing dentin bonding agent (Liner Bond II V, bond A and B mixture; Kuraray) was applied to the internal surfaces of the canal and pulp chamber and thinned with a brush. A dual-polymerizing hybrid resin (Panavia F; Kuraray) was injected into the canal space.

A piece of reinforcing fiber that had been coated with bonding agent was folded as tightly as possible into the channel area using an endodontic plugger. The second piece was packed into the canal space perpendicular to the first piece, and the excess resin was removed. The resin-soaked ribbon was applied using an incremental technique. Definitive restorations of teeth were performed using a hybrid resin layer (Clearfil AP-X; A2- Shade, Kuraray). The resin restoration was polymerized with a polymerizing unit (Polofil Lux; 440 mW/cm² VOCO, Cuxhaven, Germany) for at least 2 min. All restorations were shaped and polished with contouring and polishing discs (Sof Lex; 3M ESPE). Instructions were given to the patients about brushing teeth at least 3 times per day. The color of the direct-composite restorations and of contralateral control teeth was measured using a digital technique.

Digital photographic techniques

A digital camera (Fuji S 6000; Fuji Corp, Tokyo, Japan) fixed on a tripod perpendicular to the patient and 40 cm from the patient's head was used to obtain images of the direct-composite restorations. After 24-h polymerization of composite resin restorations, these were taken on a clear day at 11: 00 a.m. with indirect daylight, and all were recorded as TIFF images. The exposure parameters were calibrated the same for all exposures. The images were then displayed on a 24-bit resolution screen and analyzed using Adobe Photoshop CC. During the analysis, fixed circular areas approximately 74 pixels in diameter were selected in the middle third of each tooth (both the

Table 1. Luminosity and RGB values of zircon-rich fiberglass posts (Z).

Z	Luminosity		Red		Green		Blue	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	198.4	6.8	218.5	4.8	193.6	8.0	170.5	7.5
2	201.5	10.5	192.0	9.4	208.4	10.8	190.7	12.3
3	182.6	10.8	173.5	10.4	189.8	10.9	170.9	14.5
4	175.9	11.2	164.4	7.8	181.7	12.7	175.9	13.9
5	186.4	13.2	176.5	9.5	191.7	15.1	184.9	14.8
6	171.7	5.7	169.6	6.7	176.8	6.6	150.6	14.9
7	182.1	8.6	176.4	5.8	187.9	10.5	166.8	17.6
8	213.1	14.6	217.2	9.8	214.8	15.9	193.8	23.7
9	199.4	7.8	215.4	5.4	195.6	7.5	168.5	13.9
10	201.2	12.5	207.8	9.5	198.8	7.9	178.9	11.1
11	168.8	12.5	165.7	8.8	172.3	9.1	159.9	6.8

Table 2. L*a*b* values of zircon-rich fiberglass posts (Z).

Z	L*		a*		b*	
	Mean	SD	Mean	SD	Mean	SD
1	203.9	6.5	134.5	2.0	143.1	1.4
2	219.1	9.8	119.4	1.4	134.3	1.8
3	191.6	10.0	119.2	2.2	135.1	3.3
4	184.8	10.9	120.9	2.2	128.8	2.3
5	194.4	12.9	121.7	2.5	129.6	1.8
6	181.1	5.4	122.0	2.6	140.6	6.1
7	190.9	8.4	121.1	3.2	137.3	5.4
8	218.5	13.3	126.3	2.6	138.8	5.6
9	206.7	7.9	132.5	2.0	141.1	3.9
10	224.7	7.9	129.0	2.7	143.1	2.3
11	198.0	9.1	123.5	2.4	146.8	3.1

contralateral control and restored teeth). The L*a*b* and RGB values of these areas were measured, and the mean values were recorded using the histogram function of Adobe Photoshop.

Measuring color values

Once the relevant image components had been selected, the histogram command was used to extract data. The histogram command in Photoshop provides means and dispersion measures for the numerical parameters of several different color-digitization systems.

Two color systems were investigated. One was the RGB system, in which color is defined in terms of red, green, and blue pixel

intensity on a scale from 0 to 255. The other was the CIELAB system, in which colors are defined in terms of an L* (lightness) parameter and 2 descriptors of hue (a* and b*) on a similar 0–255 scale. The values of the 2 systems were compared.

The color difference, recorded in ΔE units, was calculated using the following formula (CIE1976 L*a*b* colorimetric system) [22]:

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

where ΔL*, Δa*, and Δb* are the differences between the mean L*, a*, and b*, respectively, of the direct-composite restorations and contralateral control teeth.

Table 3. Luminosity and RGB values of contralateral control teeth (Cz)

Cz	Luminosity		Red		Green		Blue	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	183.9	9.2	211.1	7.3	175.5	10.4	155.1	11.3
2	218.9	3.8	213.8	4.5	223.4	4.3	207.7	8.4
3	177.0	8.1	168.9	5.9	182.6	9.3	170.7	10.4
4	166.6	12.4	153.8	7.4	178.7	14.1	162.5	18.7
5	185.9	10.3	176.8	6.7	190.2	11.5	188.0	16.8
6	167.9	8.8	165.9	5.9	172.9	10.2	146.7	16.0
7	189.9	14.6	187.7	11.1	194.8	15.8	169.5	23.7
8	195.3	11.3	199.3	7.7	196.2	12.4	189.8	18.4
9	176.9	7.5	198.9	6.5	185.9	6.4	159.8	12.9
10	195.5	11.2	192.6	8.9	186.8	8.5	156.8	10.2
11	165.7	11.2	163.1	7.9	170.4	8.1	154.1	5.8

Table 4. L*a*b* values of zircon-rich fiberglass posts (Cz).

Cz	L*		a*		b*	
	Mean	SD	Mean	SD	Mean	SD
1	199.8	8.6	139.2	2.5	143.6	2.6
2	224.3	3.4	121.9	1.8	134.1	2.9
3	185.8	7.9	121.0	2.2	131.9	2.1
4	175.6	12.4	125.4	2.8	130.7	4.1
5	193.7	9.	122.9	2.1	127.5	4.1
6	177.4	8.6	122.1	2.3	140.7	4.9
7	197.9	13.5	122.2	2.9	140.0	5.9
8	212.5	10.6	127.1	2.0	136.8	4.4
9	204.4	6.8	135.4	2.4	139.1	3.6
10	219.7	8.0	119.7	2.0	145.8	2.9
11	193.2	8.9	118.9	2.4	139.8	3.9

Descriptive statistical analysis was performed for the CIE L*a*b* values, including the mean and standard deviation (SD) for each group, using *t* tests (version 13.0; SPSS, Chicago, IL). Color differences (ΔE) for the average L*a*b* color parameters between every pair of groups were calculated. The ΔE values were used to identify any difference greater than 3, which is the average acceptable color difference of clinical significance according to Yap et al. [26].

Results

The digital color analysis program gave identical luminosity, RGB, and L*a*b* values for selected areas with the same

coordinate points. The results of the digital color measurements of zircon-rich fiberglass posts (Z) (n=11) and contralateral control teeth (Cz) (n=11) are presented in Tables 1–4. There were no significant differences in the color luminosity (lum), RGB, or L*a*b* values between the zircon-rich fiberglass posts and contralateral control teeth ($P>.05$) (Table 5). The digital color analysis program gave identical luminosity, RGB, and L*a*b* values for the selected areas at the same coordinates. The results of the digital color measurements of the polyethylene fiber posts (P) (n=11) and contralateral control teeth (Cp) (n=11) are presented in Tables 6–9.

There were no significant differences in the color luminosity (lum), RGB, or L*b* values between the polyethylene fiber

Table 5. Paired Samples Test results between zircon-rich fiberglass posts (Z) and contralateral control teeth.

	Pair-wise differences					T	df	Sig. (2-tailed)
	Mean	SD	Std. error mean	95% Confidence interval of the difference				
				Lower	Upper			
Z-L*/Cz-L*	2.65909	4.87888	1.47104	-0.61859	5.93677	1.808	10	0.101
Z-a*/Cz-a*	-0.52909	4.11242	1.23994	-3.29185	2.23367	-0.427	10	0.679
Z-b*/Cz-b*	0.76909	2.86772	.86465	-1.15747	2.69565	0.889	10	0.395
Z-lum/Cp-lum	5.22909	11.29553	3.40573	-2.35935	12.81753	1.535	10	0.156
Z-R/Cz-R	4.09455	12.03800	3.62959	-3.99270	12.18179	1.128	10	0.286
Z-G/Cz-G	4.92182	10.01022	3.01819	-1.80314	11.64677	1.631	10	0.134
Z-B/Cz-B	4.66273	10.58013	3.19003	-2.44510	11.77056	1.462	10	0.175

Table 6. Luminosity and RGB values of polyethylene fiber posts (P).

P	Luminosity		Red		Green		Blue	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	167.5	8.9	146.5	7.4	179.2	9.9	161.8	11.2
2	189.4	10.2	178.2	8.7	201.0	10.4	195.1	15.8
3	139.2	6.3	182.3	6.0	119.3	6.6	129.6	7.6
4	195.8	19.9	231.5	17.3	176.8	20.9	199.7	23.3
5	187.6	7.5	236.4	8.2	163.7	7.2	182.1	8.9
6	202.1	9.7	247.6	6.1	182.7	11.3	182.5	13.9
7	203.8	9.9	248.1	5.9	185.0	11.6	184.4	14.5
8	220.1	14.4	220.4	16.8	227.2	13.7	203.2	14.6
9	167.4	5.4	169.2	4.4	167.4	5.8	162.5	8.2
10	207.8	2.8	200.4	2.8	215.3	3.1	188.7	3.3
11	209.1	2.9	208.7	2.8	214.5	3.4	182.7	6.0

posts and contralateral control teeth ($P > .05$). However, there was a significant difference between the color a^* values of the polyethylene fiber posts and contralateral control teeth ($P > .05$; Table 10). The color differences (ΔE) between the zircon-rich fiberglass posts, polyethylene fiber posts, and contralateral teeth are presented in Table 11.

The mean ΔE value for the color comparison between the zircon-rich fiberglass posts and contralateral control teeth was 4.3266 and the mean ΔE value for the color comparison between the polyethylene fiber posts and contralateral teeth was 5.5972. The highest and lowest ΔE values and standard deviation are shown in Table 11. No significant color differences (ΔE) were found between the zircon-rich fiberglass posts or polyethylene fiber posts and the contralateral teeth ($P > .05$; Table 12).

Discussion

Esthetic demands have increased the use of tooth-colored post systems. When restoring incisors with tooth-colored restorations, tooth-colored posts should be used to achieve the optimal esthetic appearance [10].

Restoration of selected endodontically-treated teeth using fiber posts and resin-based composites with no crown coverage is considered an economical, tooth-saving alternative to more expensive and less-conservative crown coverage [4]. In addition, restoration using adhesive techniques allows preservation of the maximum amount of sound tooth structure [4]. Therefore, our study examined incisors restored using esthetic posts and direct-composite restorative materials.

Table 7. L*a*b* values of polyethylene fiber posts (P).

P	L*		a*		b*	
	Mean	SD	Mean	SD	Mean	SD
1	178.9	8.8	113.8	1.6	133.1	3.8
2	210.1	9.6	114.2	1.7	132.2	4.6
3	145.7	6.1	154.4	1.5	133.1	1.4
4	198.9	18.5	151.4	2.2	124.6	2.6
5	191.7	6.9	157.8	1.4	130.1	1.8
6	205.2	8.7	152.2	2.9	137.9	3.0
7	207.2	8.8	151.5	3.1	137.7	3.2
8	227.0	12.8	119.6	2.6	138.1	2.5
9	175.1	5.2	128.0	1.3	130.8	2.2
10	205.3	2.6	119.2	1.0	139.4	1.1
11	216.0	2.7	121.9	1.4	143.0	2.6

Table 8. Luminosity and RGB values of contralateral control teeth (Cp)

Cp	Luminosity		Red		Green		Blue	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	165.3	8.4	137.6	5.9	163.8	9.2	157.5	13.2
2	210.6	10.6	189.6	10.2	220.5	10.6	214.2	14.9
3	143.2	12.6	187.6	10.4	122.6	13.1	132.5	18.1
4	205.9	13.3	241.9	7.9	187.1	16.1	208.5	15.0
5	194.1	6.7	246.5	6.6	167.7	6.7	192.2	10.7
6	180.8	12.1	228.5	9.5	160.6	13.3	158.9	15.9
7	198.6	15.7	234.1	11.8	179.1	17.2	179.4	19.9
8	233.4	7.5	227.2	9.5	239.3	6.8	217.9	11.4
9	169.7	9.3	176.8	8.5	169.2	9.4	152.0	12.9
10	200.8	4.6	196.5	3.7	206.9	5.1	180.8	7.9
11	208.6	5.6	205.6	5.2	212.6	6.2	185.4	7.6

One of the goals of instrumental color measurement in dentistry is the development of valid intraoral optical electronic determination of the color or shade of teeth [34]. This kind of technology removes the shade selection from the subjective, visual process variable. The practical application of technology that quantifies color and color difference first requires the establishment of clinical parameters, some of which are visual awards [34]. Determining the color difference between only 2 samples has little clinical value, without understanding the magnitude of the color difference (visibility tolerances) visually perceptible and the unacceptable change in dental esthetics (acceptability tolerances) [34].

Çal et al. [20] concluded that the Adobe Photoshop 4.0 color analysis program could analyze the color of images correctly. In another study, Çal et al. [28] concluded that color measurements obtained using digital analysis concurred with spectrophotometric evaluations with respect to a* and b* values. We used the program Adobe Photoshop 7.0 to obtain color measurements.

In the present study, the digital color analysis program showed no significant difference in terms of the CIE L*a*b*, luminosity, and RGB color coordinates between the zircon-rich fiber-glass post group and contralateral control teeth; however, comparisons between polyethylene fiber posts and contralateral control teeth revealed significant differences in the a* values

Table 9. L*a*b* values of contralateral control teeth (Cp)

Cp	L*		a*		b*	
	Mean	SD	Mean	SD	Mean	SD
1	176.4	8.4	117.5	1.5	128.1	3.2
2	218.1	9.6	116.5	1.4	127.5	3.4
3	149.5	11.8	155.1	1.9	133.7	4.2
4	207.7	12.3	150.8	4.0	125.3	2.2
5	206.8	6.0	160.3	1.5	127.9	3.0
6	195.6	11.1	153.9	2.7	139.6	3.2
7	194.6	14.0	152.6	3.3	137.8	3.3
8	237.7	6.4	121.1	2.3	136.9	3.6
9	177.5	8.6	128.6	1.3	137.9	2.9
10	208.4	4.2	120.9	1.5	139.8	2.4
11	215.6	5.2	123.2	1.7	135.7	2.0

Table 10. Paired Samples Test results between polyethylene fiber posts (P) and contralateral control teeth (Cp)

	Pair-wise differences						T	df	Sig. (2-tailed)
	Mean	SD	Std. error mean	95% Confidence interval of the difference					
				Lower	Upper				
P-L/Cp-L	-2.42727	8.36573	2.52236	-8.04745	3.19290	-0.962	10	0.359	
P-a/Cp-a	-1.48727	1.13517	0.34227	-2.24989	-0.72466	-4.345	10	0.001	
P-b/Cp-b	0.87818	3.90330	1.17689	-1.74409	3.50045	0.746	10	0.473	
P-lum/Cp-lum	-1.87727	11.33979	3.41908	-9.49545	5.74090	-0.549	10	0.595	
P-R/Cp-R	-0.23727	10.64454	3.20945	-7.38837	6.91383	-0.074	10	0.943	
P-G/Cp-G	0.24091	12.24595	3.69229	-7.98603	8.46785	0.065	10	0.949	
P-B/Cp-B	-0.67545	12.42200	3.74537	-9.02067	7.66976	-0.180	10	0.860	

($P > .05$), although the differences were too small to recognize clinically because polyethylene fiber posts become translucent after polymerization.

Several studies have been tried to determine color-matching tolerances. Kuehni and Markus [35] provided a detection tolerance of 1 ΔE unit for 50% of observers using textile samples and matte paints under optimal viewing conditions. Seghi et al. [13], using monochromatic porcelain discs, found that a color difference of 2 ΔE units was correctly evaluated by 100% of *in vitro* observers. Acceptability tolerances have also been investigated under ideal monitoring conditions. Ruyter et al. [36] reported that with monochromatic composite resin discs, 50% of the observers saw the separation of the composite specimens as unacceptable when the color difference was approximately 3.3 ΔE units. Johnston and Kao [16] noted that

the average color difference between compared teeth rated as matching in an oral environment was 3.7 ΔE units. This *in vivo* study also reported that the average color difference between compared teeth rated as a mismatch within the normal range of tooth color in an oral environment was 6.8 ΔE units.

The present study revealed ΔE values ranging from 0.37 to 9.21 in comparisons between zircon-rich fiberglass posts and contralateral control teeth and from 2.68 to 10.90 between polyethylene fiber posts and contralateral control teeth (Table 3). While some ΔE values in this study fell within the perceivable range reported by Ruyter et al. [36] (3.3 ΔE), the majority exceeded 3.3 ΔE . This incongruity may have resulted from intra-oral conditions and the sensitivity of an *in vitro* study. However, the ΔE values were compatible with the *in vivo* findings of Johnston and Kao [16] (mean color difference of 3.7 ΔE and

Table 11. Color differences (ΔE) between zircon-rich fiberglass posts, polyethylene fiber posts, and contralateral teeth.

	$Z_{\Delta E}$	$P_{\Delta E}$
1	0.4	2.7
2	6.7	5.0
3	5.0	3.0
4	3.4	6.2
5	1.0	10.9
6	2.5	4.9
7	7.0	8.2
8	5.1	8.4
9	1.3	5.7
10	6.5	3.3
11	9.2	3.4

range 0.5–12.5). The color differences (ΔE) among the zircon-rich fiberglass posts, polyethylene fiber posts, and contralateral control teeth were not significant.

The instrument used for color detection was not recommended because it gives edge-loss errors that can be misleading. This means that the potential error source may be responsible for the large standard deviations associated with the reported ΔE , CIE $L^*a^*b^*$, luminosity, and RGB values.

In all dental studies in which color is assessed, the results should be compared by selecting the level of perceivability or acceptability tolerance. If the difference in color is perceivable by an observer and it is not known whether it is clinically acceptable, quantification of this difference does not make much sense. As long as color differences (ΔE units) do not constitute tolerances for perceivability and acceptability, the results of the research can be evaluated for statistical significance, but not interpreted clinically [12]. We attempted to determine the effect of 2 esthetic post-and-core materials on the final shade of definitive restorations. The definitive restorations were equally affected by both materials. Both materials can be used reliably in clinical practice [2,6,11,29]. However, further research should focus on the effects of intraoral conditions.

Conclusions

1. There were no significant differences in the color luminosity (lum), RGB, or $L^*a^*b^*$ values between the zircon-rich fiberglass posts and contralateral control teeth.
2. There were no significant differences in the color luminosity (lum), RGB, or $L^*a^*b^*$ values between the polyethylene fiber posts and contralateral control teeth. However, there was a significant difference between the color a^* values of the polyethylene fiber posts and contralateral control teeth.
3. No significant color differences (ΔE) were found between zircon-rich fiberglass posts or polyethylene fiber posts and contralateral teeth.

Table 12. Paired Samples Test results of color differences between zircon-rich fiberglass posts, polyethylene fiber posts.

	Pair-wise differences						T	df	Sig. (2-tailed)
	Mean	SD	Std. error mean	95% Confidence interval of the difference					
				Lower	Upper				
$Z_{\Delta E} - P_{\Delta E}$	-1.27054	4.27242	1.28818	-4.14079	1.59971	-0.986	10	0.347	

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