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Comparison of Color Accuracy between Natural Dentin Substrate and Three Dentin Porcelain Brands of Glass-Matrix Ceramic System (Digital Image Analysis)

Comparação da Precisão de Cor entre Substrato Dentina Natural e Três Marcas de Porcelana Dentina do Sistema Cerâmico Glass-Matrix (Análise de Imagem Digital)

Comparación de la Precisión del Color entre el Sustrato de Dentina Natural y Tres Marcas de Porcelana de Dentina del Sistema Cerámico de Matriz de Vidrio (Análisis de Imágenes Digitales)

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Abstract
Purpose: The purpose of this laboratory study was to differentiate the color of natural dentin (ND) and dentin porcelain (DP) by using three brands of Glass-Matrix Ceramic System (GMCS) by parametric CIE L*, a*, b* system. Materials and methods: An extracted human upper central incisor was prepared as a control group. Uniformly thick dentin specimen was taken from the middle coronal third of the labial half longitudinally. Twelve disks of GMCS dentin porcelain were fabricated according to manufactures' instructions by using conventional powder/slurry technique, 4 disks for each group; Feldspathic ceramic VITA VMK 95 (VMK), Leucite-based ceramic VITA VM9 (VM9), and Fluorapatite-based ceramic IPS e.max Ceram IVOCLAR (IEC). ND and DP specimens' thickness were (8×1 mm, shade A3) and (n=4). A digital camera was used to take samples' photos while the color readings were obtained by graphic software. The specimens' colors were measured, and the data were statistically evaluated using Levene's test, One-way ANOVA, and Post Hoc Multiple Comparisons. Results: Parametric CIE L*, a*, b*, and ΔE values of all ceramic disks compared to ND were significantly different even within ceramic brands (P<.05), ΔE were ND > IEC > VMK > VM9. Conclusions: To reproduce ND color by DP needs proper color shade guide selection due to color differences from one brand to another even in the same shade guide tab. Clinical Significance: There is a lack of information on how identical natural dentin color to dentin porcelain is at the same shade guide.
Keywords: Natural dentin; Dentin porcelain; Color accuracy; Digital image analysis.

Resumo
Objetivo: O objetivo deste estudo laboratorial foi diferenciar a cor da dentina natural (ND) e da porcelana dentinária (DP) usando três marcas de Glass-Matrix Ceramic System (GMCS) pelo sistema paramétrico CIE L*, a*, b* . Materiais e métodos: Um incisivo central superior humano extraído foi preparado como grupo controle. Amostras de dentina uniformemente espessas foram retiradas do terço coronal médio da metade labial longitudinalmente. Doze discos de porcelana de dentina GMCS foram fabricados de acordo com as instruções do fabricante usando a técnica convencional de pó/pasta, 4 discos para cada grupo; Cerâmica feldspática VITA VMK 95 (VMK), cerâmica à base de leucita VITA VM9 (VM9) e cerâmica à base de fluorapatita IPS e.max Ceram IVOCLAR (IEC). As espessuras dos corpos de prova ND e DP foram (8×1 mm, cor A3) e (n=4). Uma câmera digital foi usada para tirar fotos das amostras enquanto as leituras de cores foram obtidas por software gráfico. As cores dos espécimes foram medidas e os dados foram avaliados estatisticamente usando o teste de Levene, One-way ANOVA e Post Hoc Multiple Comparisons. Resultados: Os valores paramétricos CIE L*, a*, b* e ΔE de todos os discos cerâmicos em comparação com ND foram significativamente diferentes mesmo dentro das marcas de cerâmica (P<0,05), ΔE foram ND > IEC > VMK > VM9. Conclusões: Para reproduzir a cor ND por DP, é necessário selecionar a escala de cores adequada devido às diferenças de cor de uma marca para outra, mesmo na mesma guia de escala de cores. Significado Clínico: Há uma falta de informação sobre como a cor de dentina natural é idêntica à da porcelana de dentina na mesma escala de cores.
Palavras-chave: Dentina natural; Porcelanato dentina; Precisão de cores; Análise de imagens digitais.

Resumen
Propósito: El propósito de este estudio de laboratorio fue diferenciar el color de la dentina natural (ND) y la porcelana de dentina (DP) mediante el uso de tres marcas de Glass-Matrix Ceramic System (GMCS) mediante el sistema paramétrico CIE L*, a*, b*. Materiales y métodos: Se preparó un incisivo central superior humano extraído como grupo de control. Se tomó una muestra de dentina uniformemente gruesa del tercio medio coronal de la mitad labial longitudinalmente. Se fabricaron doce discos de porcelana de dentina GMCS de acuerdo con las instrucciones del fabricante utilizando la técnica convencional de polvo/lechada, 4 discos para cada grupo; Cerámica feldespática VITA VMK 95 (VMK), cerámica a base de leucita VITA VM9 (VM9) y cerámica a base de fluorapatita IPS e.max Ceram IVOCLAR (IEC). Los espesores de las muestras ND y DP fueron (8 × 1 mm, tono A3) y (n = 4). Se utilizó una cámara digital para tomar fotografías de las muestras mientras que las lecturas de color se obtenían mediante un software gráfico. Se midieron los colores de los especímenes y los datos se evaluaron estadísticamente usando la prueba de Levene, ANOVA unidireccional y comparaciones múltiples post hoc. Resultados: Los valores paramétricos CIE L*, a*, b* y ΔE de todos los discos cerámicos en comparación con ND fueron significativamente diferentes incluso dentro de las marcas cerámicas (P<.05), ΔE fue ND > IEC > VMK > VM9. Conclusiones: Para reproducir el color ND por DP, se necesita una selección adecuada de la guía de colores debido a las diferencias de color de una marca a otra, incluso en la misma pestaña de la guía de colores. Importancia clínica: Hay una falta de información sobre qué tan idéntico es el color de la dentina natural a la porcelana de dentina en la misma guía de colores.
Palabras clave: Dentina natural; Porcelana de dentina; Precisión de color; Análisis de imágenes digitales.

1. Introduction

Dentin is bone-like tissue that forms the bulk of tooth hard structures (enamel, dentin and cementum). It is covered by enamel at the crown, a highly mineralized, protective layer, and surrounded by cementum at the root. Besides, the tooth contains dental pulp in its central part, which contains nerves and a vascular network. Histologically, dentin is a complex tissue containing apatite as the mineral phase, a collagen matrix and non-collagenous contents (Bertassoni et al. 2009; Omelon & Grynpas, 2008).

In modern dentistry to achieve the appearance between the natural teeth and artificial restorative materials is a very important issue (Li, Yu & Wang, 2009), so there are many available types of ceramic material systems with various mechanical and physical properties (Holand et al. 2006), especially ceramic restorations without underlying metal that allow greater light transmission through the crown, so the color and translucency are improved of the restoration and have been widely used, mostly in anterior restorations (Barath et al. 2003; de Azevedo et al. 2011; Dede et al. 2013).

Using Glass-matrix ceramic systems in dentistry has recently increased, especially because of the general aesthetic appearance and its widely used in prosthetic dentistry due to the continuous improvements of their mechanical properties associated with better microstructures and new processing techniques (Bajraktarova-Valjakova et al. 2018). The adequate mechanical properties of these materials reflect the good longevity of such dental restorations (Holand et al. 2006; Anusavice, Kakar & Ferree, 2007; Höland, 2012). Good aesthetic quality is another factor that contributes to the attractiveness of glass-ceramics to clinicians and technicians (Anusavice, S.C.P.H, 2012; Seghi, R.R., Johnston & O'Brien, 1986).

To achieve proper appearance between the natural teeth and artificial restorative materials is a complex process in dentistry, depending on many factors. In addition to opacity, shade, adhesive and substrate color and thickness, lighting conditions, translucency, light scattering, and the human eye and brain influence the overall perception of tooth color. The esthetic result also depends upon the dental technicians' experience, skill, and motivation. Other factors, including porcelain brands, batches, fabrication methods, firing temperature, and repeating ceramic firings (Hammad, & Stein, 1991; Shokry et al. 2006; Barghi & Goldberg 1977; Ozturk et al. 2008; Sahin et al. 2010; Culpepper, 1970; CIE, 1971; Van der Burgt et al. 1990).

Color assessment is possible via several methods including visual assessment with shade guides, spectrophotometry, colorimetry and computer analysis of digital images. These methods have successfully been used to measure longitudinal tooth color changes when the dentition has undergone tooth whitening procedures (Joiner, 2004).

By comparing the tooth with standard color tooth shade guides, visual color determination is the most frequently applied method in dentistry (Van der Burgt et al. 1990); instrumental colorimetric techniques have been used within the dental field to achieve an objective and quantitative evaluation of color differences.

Digital imaging has the potential for use in dental shade determination. This is obvious in situations where the tooth color, including a description of effects, such as enamel hypoplasia or decalcification, and translucency must be communicated between the clinician and the laboratory technician. Furthermore, digitized images can be transmitted electronically, which along with the widespread use of the Internet, makes this option advantageous (Jarad, Russell & Moss, 2005; Wee et al. 2006).

Instrumental color determination has been introduced recently. In previous investigations, the use of colorimeters or spectrophotometers has been shown to be efficient (Ishikawa-Nagai et al. 2005; Paul et al. 2004; Dancy et al. 2003); however, these devices are rather expensive, which may restrict their extension to dental practices. Therefore, development of a simple shade selection system with high reliability that is usable in dental practice would be beneficial.

There is an informational deficiency on how the color of dentin porcelain is identical to natural dentin. The purpose of this study was to reproduce ceramic dentin similar to dentin by using three brands of glass-matrix ceramic system; VITA VMK 95, VITA VM9, and IPS e.max Ceram IVOCLAR. The null hypothesis was that no difference existed between natural dentin and dentin porcelain, either visual shade matching or digital photographs..

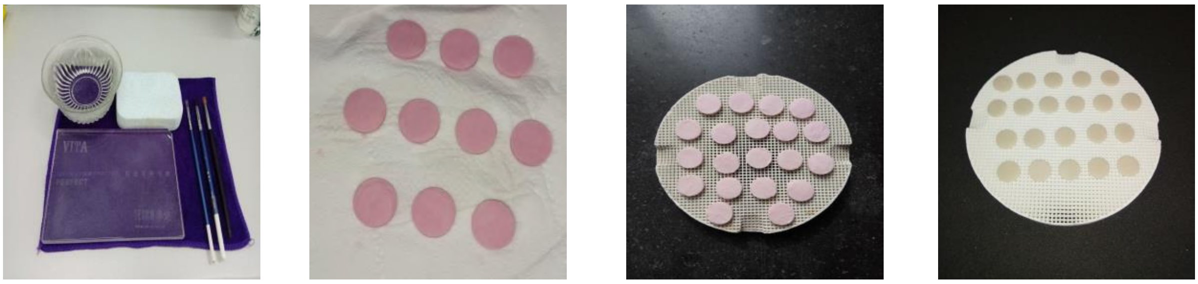
2. Methodology

One accidentally extracted upper central incisor shade A3.5 was intact, fresh and free of conservative prosthetic restoration, caries, or pathological discoloration. Remove enamel and pulp tissues carefully, first sectioning tooth in mesiodistal direction with its long axis by diamond disk at low speed (250 r/min) under constant water cooling. The incisal and labial enamel was removed by diamond bur with low speed and coolant till midcoronal dentin was exposed. Then, dentin slice (1.5 mm thick and 10 mm in diameter) and manually polished under constant pressure with wet silicon carbide sheets 600-, 800-, 1000- grit; (Siawat WA, Zurich, Switzerland) for both sides, till reached uniformly thick specimens (1 mm thick and 8 mm in diameter), as measured with an electronic digital caliper; (IDU, Mitutoyo Corp., Kawasaki, Japan). The specimen was ultrasonically cleaned in distilled water for 10 minutes and stored in normal saline at room temperature for 24 hours for rehydration and was removed from the water and dried just before the taken photos were made. CIE Lab color coordinates of dentin and ceramic specimens against black background ($L^*=2$, $a^*=1.1$; $b^*= -1.1$).

After preparation, the dentin specimen color was A3 and was compared with 3 base dentin ceramic brands of Glass-matrix system; (N=4) shade A3; VITA Classical shade guide (Vita Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany) and thickness similar to natural dentin disk.

A custom-made metallic mold with a cavity of 10 mm diameter and 2 mm thickness was fabricated to standardized disk thicknesses (8 × 1 mm), shade A3. Twelve disk-shaped dentin porcelain shade A3 specimen was fabricated Using condensation/sintering technique and packed in the metallic mold cavity till filling; proper drying and pressure were applied before the specimen was removed from the mold with slight finger pressure and put on the honey-comb tray then put in a vacuum furnace for firing procedure. Figure 1.

Figure 1 - Ceramic disks fabrication.



Source: Authors.

In Vita VMK95 (VITA VACUMAT 6000 MP; start temperature 600°C, pre-drying time 6min., heating time 6min., temperature rise rate 55°C/min., temperature 930°C, holding time for end temperature 1min., vacuum holding time 6min.). After cooling to room temperature, a digital caliper was used to confirm the thickness of each disk (IDU, Mitutoyo Corp., Kawasaki, Japan). Correction procedures for all specimens were by diamond burs (Woosin Diamond 600 grit), and sandpapers sequentially were used 600-, 800-, 1000- grit (Siawat WA, Zurich, Switzerland) for both sides, ultrasonically cleaned in distilled water for 10 minutes and air-dried.

For Vita VM9, specimens put in the same vacuum furnace, for firing1 (start temperature 500°C, pre-drying time 6min., heating time 7.27min., temperature rise rate 55°C/min., temperature 910°C, holding time for end temperature 1min., vacuum holding time 7.27min.). For specimens firing2 (start temperature 500°C, pre-drying time 2min., heating time 8.11min., temperature rise rate 55°C/min., temperature 950°C, holding time for end temperature 1min., vacuum holding time 8.11min.).

Ivoclar IPS e.max Ceram specimens were put in the vacuum furnace for firing (Programat P300; Ivoclar Vivadent AG, Schaan, Liechtenstein; start temperature 403°C, closing time 8min., heating rate 50°C/min., firing temperature 780°C, holding time 1min., vacuum1 temperature 450°C, vacuum2 temperature 779°C).

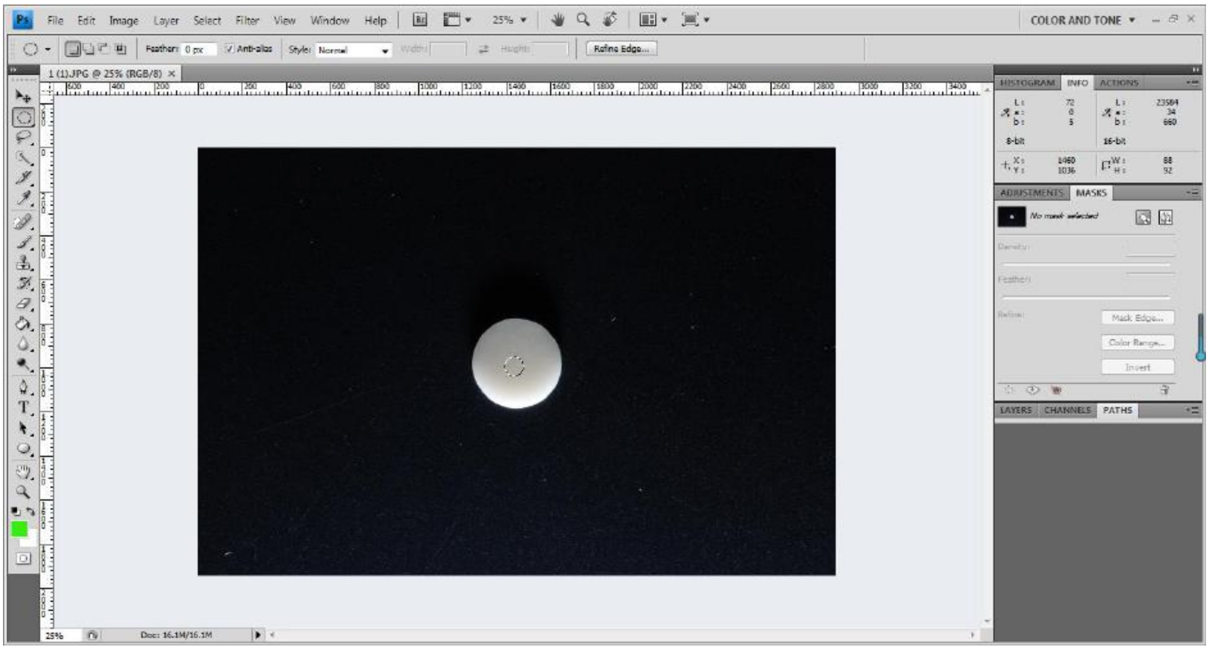
The photos' shooting was taken by a digital camera (NIKON D80) with one para-flash (YN560); the camera that was used in this study, featured in manual capture mode (f-stop = f/8, exposure time = 1/100 sec., focal length = 105 mm, night mode, and max. aperture = 3.4). The digital camera was fixed on a tripod, and the lens is perpendicular to the sample, which is located between the anterior two arms of the tripod, shooting distance of 40cm. Para-flash was in front of the posterior arm of the tripod on the black background, which is in a straight line with the sample, specimen, camera, para-flash, black background and distances were standardized during specimens' shootings. Figure 2.

To calculate the CIE L*, a*, and b* values of photos, the captured photos were outputted in the default jpeg format with a size 2896 × 1944 pixels and opened by (Ps ADOBE® PHOTOSHOP® CS4 Middle Eastern Version 11.0), during the analysis procedures, circle area of 1mm diameter was chosen from the center and the values of this particular area was recorded. The same procedures were repeated for the other remaining photos using the same coordinate points. Figure 3.

Figure 2 - Sample and camera set up for recording of the digital photographs.

Source: Authors.

Figure 3 - Computer screen capture of the digital photograph and shade in the Ps ADOBE® PHOTOSHOP® CS4 software computer program.



Source: Authors.

The specimens' data were statistically analyzed using (IBM SPSS Statistics v20.0; IBM Corp). To test the normal distribution of the variables, the Levene test of equality of error variances was used and showed the normal distribution of the variables. Descriptive analysis was used to obtain the mean values. One-way ANOVA was used to compare between L*, a*, and b* for each group, multifactorial analysis of variance (ANOVA) was used to analyze the color differences between groups. Tukey test (α=0.05) if any statically significant effect was found less than 0.05.

3. Results

The mean values and multiple comparison test results for CIE L*, a*, and b* for natural dentin and ceramic disks are listed in Table 1.

Table 1 - Mean values of CIE L*, a*, and b* values of ND, Natural Dentine; VMK, VMK95; VM9; IEC,IPS e.max Ceram.

System	Property		
	L*	a*	b*
ND	71.2	-3.5	-4
VMK	65.2	-0.2	2.4
VM9	59.2	3	3.8
IEC	66.2	-0.4	2

Source: Authors.

All values were statically significant differences (P<.05), although the shade of ceramic disks was based on the Vitapan Classical shade guide (A3) and corresponding Vitapan 3D-Master shade guide (3M2). Lightening and greenness-blueness of natural dentin. In VMK 95 L*, a* was lesser than natural dentin, but b* was higher (yellowish); in VM9 specimens were the least lightening and a* were redness while b* was the highest yellowish due to b* were increased. IPS e.max Ceram L* and a* were closer to natural dentin, while b* values were decreased than VMK95.

The one-way ANOVA results of CIE L*, a*, b* and ΔE for natural dentin, VMK95, VM9, and IPS e.max Ceram are present in Table 2 and show significant differences between and within groups (p<0.05).

Table 2 - One-way ANOVA results of the color parameters for ND, Natural Dentine; VMK, VMK95; VM9; IEC, IPS e.max Ceram. p<0.05 indicates significant difference

Color Parameter		Sum of Squares	df	Mean Square	F	Sig.
L*	Between Groups	363.750	3	121.250	25.130	.000
	Within Groups	77.200	16	4.825		
A*	Between Groups	109.000	3	36.333	63.188	.000
	Within Groups	9.200	16	.575		
b	Between Groups	178.950	3	59.650	39.767	.000
	Within Groups	24.000	16	1.500		
ΔE	Between Groups	192.546	3	64.182	379.774	.000
	Within Groups	2.704	16	.169		

Source: Authors.

Post Hoc Tests of CIE L*, a*, and b* values show significant differences between sub-groups for natural dentin and each ceramic brand, which means there are also differences between the groups (ceramic brands). Table 3.

Table 3 - Post Hoc Tests of multiple comparisons for VMK, VMK95; VM9; IEC, IPS e.max Ceram in comparison to ND, Natural Dentine. * The main difference is at the 0.05 level.

Ceramic Brand	Color Parameter	Mean Difference	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
VMK	**L**	6.00000*	1.38924	.003	2.0253	9.9747
VM9		12.00000*	1.38924	.000	8.0253	15.9747
IEC		5.00000*	1.38924	.012	1.0253	8.9747
VMK	**a**	-3.40000-*	.47958	.000	-4.7721	-2.0279
VM9		-6.60000-*	.47958	.000	-7.9721	-5.2279
IEC		-3.20000-*	.47958	.000	-4.5721	-1.8279
VMK	**b**	-6.40000-*	.77460	.000	-8.6161	-4.1839
VM9		-7.80000-*	.77460	.000	-10.0161	-5.5839
IEC		-6.00000-*	.77460	.000	-8.2161	-3.7839
VMK	**ΔE**	5.62000*	.26000	.000	4.8761	6.3639
VM9		8.60000*	.26000	.000	7.8561	9.3439
IEC		4.04000*	.26000	.000	3.2961	4.7839

ΔE values were calculated between groups, and the average was between 0.76 and 9.36 (ND > IEC > VMK >VM9).
Source: Authors.

4. Discussion

This laboratory study showed color differences between natural dentin and 3 brands of dentin porcelain of Glass-matrix ceramic system and color assisting with the PHOTOSHOP® CS4, a commercially available graphic software program. The accuracy of PHOTOSHOP® CS4 is reliable assistance to visual color assessment compared with conventional visual methods. This photographic shade analysis system does not improve with conventional visual shade matching results. If the conventional visual shade matching method is considered the gold standard, the capability of this photographic shade analysis system to shade match has not been achieved accurately. To reproduce natural dentin color by dentin porcelain is meaningless without using other additives like ceramic core, ceramic enamel, or pigments. This laboratory study suggests that base dentin porcelain color differs from one brand to another, i.e., communication between dentist and dental technician is a critical issue.

Because of the continual advances in mechanical qualities associated with improved microstructures and novel processing processes, glass-ceramics are widely employed in prosthetic dentistry. These materials' appropriate mechanical qualities are seen in the long-term durability of dental restorations. Another feature that contributes to the appeal of glass-porcelains to physicians is their high aesthetic quality (Holand et al. 2006).

The results of this study totally refused the hypothesis because natural dentin and dentin porcelain colors differ even in the same shade (A3 or 3M2), also between the ceramic brands themselves.

Dentin constitutes the main bulk of a tooth and is mainly responsible for its color (O'Brien, Fan & Groh, 1994). The color in the natural tooth occurs from the light directly reflected from the dentin (Heffernan et al. 2002). Color differences between opaque and dentin layers have been mentioned as being at ΔE = 6.76 in CIE L*a*b* system because of the underlying metal and opaque layers (Seghi, Johnston & O'Brien, 1989).

Our study was in accordance with Jarad et al. who used the digital color analysis, and stated that the computer method greatly improved the observers' shade matching performance. His study also suggested that the digital camera can be utilized to take color measurements in dental clinics (Jarad, Russell & Moss, 2005).

All-ceramic core materials have a high crystalline content to achieve more strength, leading to a high degree of opacity and interference with full ceramic material systems color (O'Brien, Fan & Groh, 1994). An increase in the total thickness affected the final appearance of the restoration (Volpato, et al. 2009; Ozakar et al. 2014). To give correct results, the

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specimen size should be considered because too small a specimen can lead to marginal loss (Ozturk et al. 2008). For that reason, specimens were prepared 8 mm in diameter to reduce margins loss during color measurements because of ceramic translucency. all specimens were modified from previous color assessment studies (Ozturk et al. 2008; Sahin et al. 2010; Celik et al. 2008; Uludag et al. 2007; Culpepper, 1970).

Color is also affected by background (Barghi & Goldberg, 1977; McLean, 1991) in this study, color measurements of ceramic specimens were carried out on a black background in order to focus only on color. Color measurement can be obtained visually. Instrumental color measurements are more widespread. Digital cameras and imaging systems aid color measurement instruments that have been widely used in dentistry (Wee et al. 2006; Honda, Prince & Fontanella, 2018; Jayachandran, 2017; Kugel, Ganz & Agarwal, 2017; Vandenberghe, 2018).

Digital photographs help contact clinicians and technicians regarding dental morphology (Jarad, Russell & Moss, 2005; Chu, Trushkowsky & Paravina, 2010; Bengel, 2003; Tam & Lee, 2012; Addy & Prayitno, 1980). As digital methods of color analysis in dental practice have become more popular (McCaslin et al. 1999; Hasegawa, Ikeda & Kawaguchi, 2000; Bentley et al. 1999). Software programs can be used effectively to analyze the color of digital images (Shono, & al. 2012). So this method was chosen to determine the color changes of different ceramic manufacturers.

There is no specific study about the differentiation between natural dentin and dentin porcelain colors; in this study, we fixed the thickness of specimens; 8 mm diameter and 1 mm thickness. When the thickness of the material increases, either by metallic ceramic cores or its ceramic thickness, the color of the materials changes. As a result, the light is absorbed and spread much, reducing reflection occurs, and the amount of light passing through the material decreases (Spink et al. 2013; Fondriest, 2003; Dozic et al. 2003) the L* value decreases as the amount of light returning from an object decreases (Dozic et al. 2003). This may explain the reduction of the L* value as the thickness of porcelain increases (Mclean, 1995). At the same time, a* and b* values increase as the thickness increases because of the increase in the thickness of the opaque layer (Barghi & Goldberg, 1977).

Recommended dentin preparation should be considered fast due to tooth color change after extraction (Soler, et al. 2017). The color must be registered before and after preparation due to the color changes in teeth at different preparation depths (Ryakhovsky & Tikhon, 2017).

The firing cycle in this study is an important issue; our study's maximum firings were under limited allowance; two times were firing.

Many studies have reported that repeating firings affect the final color of restorations, especially after the fifth firing (Sahin et al. 2010), V. Sahin et al. said that (decrease in a* and b* values).

Specimens gained less reddish and yellowish color as the firing number increased. They also reported on the effect of repetitive firings on the color of Turkom Cera alumina ceramic systems that the occurring color change is clinically acceptable ($\Delta E<3.7$). McLean (Mclean, 1995) reported no translucency loss in the repetitive firings of core materials, including a high alumina-content ceramic. And the color difference was minimal. In this study, correction procedures lead to deceased in L*a*b* values, so any correction procedures should be followed by firing or glazing (Jorgenson & Goodkind, 1979).

In this study, in accordance with these studies, As the laboratory fabrications of ceramic, the L* and b* and a* values changed. These changes in the L*, a*, and b* values were statistically significant ($P<.05$).

5. Conclusion and Final Considerations

The following conclusions are considered in this study:

- There was a significant difference in color between natural dentin and the three dentin porcelain brands.

- The color assessment of teeth and restorations could be accurately achieved by the L*, a*, and b*.
- Photographic images and graphic software can be helpful in color evaluation.

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