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Evaluation of Color Shifting in Structural Colored Resin Composite Using Two Instrumental Methods

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Aim: To observe the changes that occur in the color coordinates of Omnichroma when placed adjacent to different esthetic shades versus separately. Additionally assessing the ability of two instrumental methods in detecting these changes.
Materials and Methods: A total of 18 adjoined blocks (measuring 10x6x4mm) and 6 separate resin composite blocks (measuring 10x12x4) were prepared using two metal molds. The adjoined blocks classified according to the two levels of study: Nano-hybrid resin composite (body shade A1, A2 and A3) and measuring device (Clinical spectrophotometry and Cross-polarized digital photography).
The separate block is Omnichroma layered over 1mm Omnichroma blocker then adhered with different shades to fabricate the adjoined block.
Both blocks are then measured using two instrumental methods clinical spectrophotometry VITA Easyshade V and cross-polarized digital photography. Then ΔL, Δa and Δb were calculated to show the color change between the Omnichroma separate versus adjoined.
Statistical analysis was performed by One-way ANOVA, followed by Tukey's post hoc test. Comparison between both instrumental devices was analyzed using paired t-test.
Results: One-way ANOVA showed a statistically significant difference in the color coordinates of Omnichroma separate versus adjoined using both instrumental devices.
Paired t-test showed a statistically significant difference in measuring ΔL with all shades, Δa with A1 shade and no statistically significant difference in measuring Δb with both instrumental devices.
Conclusion: Omnichroma universal composite exhibited a pronounced red-yellow structural color when approximated to different shades. This color change was better distinguished by cross-polarized digital photography.

Keywords: Universal composite, structural color, esthetics, spectrophotometry, digital photography.

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Introduction

Color reproduction in dentistry needs knowledge, experience, and proper training. Proper understanding of the science of color, color perception, color matching & instrument usage is therefore of paramount importance.[1] Esthetic demands are increasing, adding more burden on optimal reproduction of function, shape and most importantly color of the restoration.[2,3]

The Commission Internationale de l'Eclairage (CIE), in 1931, introduced a color space in favor of standardizing instrumental color measurement. CIELAB color space consists of three coordinates L*, a* and b*. L*coordinate denotes the lightness on a scale ranging from 0 for pure black to 100 for pure white while all gray shades lie in between[4]. The chromatic characteristics defined by the a* and b* coordinates, the positive a* coordinate represents red and the negative a* represents green. The positive b* coordinate represents yellow, and the negative b* value represents blue. Each coordinate having a certain numerical value for objective standardization and proper color communication. [4–6]

Proper shade selection is one of the main determinants of color reproduction. Measurement of tooth color could be done visually through shade guides or instrumentally through spectrophotometers, colorimeters, or photographic image analysis.[7]

Subjective visual methods have limitations regarding the observer; eye fatigue, experience, light conditions, metamerism, age and color blindness.[7] Other limitations are the difference in material between the shade guide and the restoration to be used, lack of standardization, between available shade guides, as well as communication due to the absence of a numerical value to place the selection in the CIE LAB color space. Yet the human eye can detect very small differences. [7,8]

To minimize the subjectivity of shade selection, Instrumental objective methods are both more accurate and precise. Colorimeters, Spectrophotometers, Intraoral scanners, and Digital cameras paired with color measuring software are used in conjunction with visual methods for optimum results as they include the ability to quantify color. [9–12]

The implementation of the gathered information regarding the color of the tooth is applied through proper choice of materials and techniques, that is used to restore the missing tooth portion as identically as possible. The selection of the suitable inventory and technique for proper shade reproduction is challenging. On account for this, novelties of a universal composite that fits all shades is aimed.[13,14]

A structural colored composite (Tokuyama, Tokyo, Japan) with a novel filler technology was introduced. It consists of 260nm uniform sized supra-nano spherical filler of silicon dioxide (SiO_2) and of zirconium dioxide (ZrO_2) conveying a red to yellow structural color with no added pigment. Proven to acquire pronounced color adjustment potential, Omnichroma may compensate color mismatch resulting from inaccurate shade selection leading to enhanced esthetic outcome and a natural-looking restoration.[15–18]

Color change occurring in Omnichroma was tested in enclosed cavities imitating Class I or Class V defects. Yet, assessing Omnichroma in large through and through defects imitating Class III and IV defects is unmatched.

That is why the aim of this study is to investigate the effect of different shades adjoined only at one side on the shift of color coordinates of the structural colored composite, Omnichroma, layered over Omnichroma blocker (Tokuyama, Tokyo, Japan). Using both clinical spectrophotometry and cross-polarized digital photography to objectively assess the color coordinates of Omnichroma and their ability to detect these changes. The null hypothesis tested is that different adjoined shades will have no effect on the color coordinates of Omnichroma and that there is no difference between clinical spectrophotometry and cross-polarized digital photography in detecting changes in color coordinates of Omnichroma.

Materials and methods

Sample grouping and preparation

A total of 18 adjoined and 6 separate resin composite blocks were prepared. The adjoined blocks were classified according to the two levels of study: Nano-hybrid resin composite body shade (A1, A2 and A3) and the measuring device (Clinical spectrophotometry and Cross-polarized digital photography). The separate blocks were used as control to detect the Omnichroma's color coordinates separately.

A power analysis was designed to have adequate power to apply a statistical test of the null hypothesis that there is no difference between tested groups regarding color change. By adopting an alpha (α) level of 0.05 (5%), a beta (β) level of (0.2) (i.e., power=80%) and an effect size (f) of (0.522) calculated based on the results of a previous study[15,19]; the predicted total sample size (n) was found to be (24) samples (i.e., 6 samples per group). Sample size calculation was performed using G*Power version 3.1.9.7.

In this study, three types of resin composite were used: A universal resin composite Omnichroma and its opaquer Omnichroma blocker (Tokuyama, Tokyo, Japan) as well as a nanohybrid resin composite (Filtek Z250XT, 3M ESPE, St. Paul, MN, USA)[20] in the esthetic body shades A1, A2 and A3. The specimens were classified into separate and adjoined blocks. The materials used, their composition and manufacturers are presented in Table (1).

The blocks were constructed in metal molds with two different dimensions: 10mm length, 6mm width and 4 mm thickness for the separate blocks and 10mm length, 12mm width and 4mm thickness for the adjoined blocks. The separate molds are further modified by a 1 mm metal spacer for the Omnichroma blocker.

Table (1): Materials, Compositions, Manufacturer and LOT number.

Material	Type	Shade	Manufacturer	Chemical Composition	Filler Weight%
Omnichroma	Supra-nano spherical	Single Shade Universal	Tokuyama, Tokyo, Japan	Monomers: UDMA, TEGDMA. Fillers: Uniform sized supra nano spherical particles (260 nm spherical SiO2-ZrO2)	79%
Omnichroma Blocker	Supra-nano spherical	Opacifier	Tokuyama, Tokyo, Japan	Monomers: Bis-GMA, TEGDMA. Filler: Uniform sized supra nano spherical particles (SiO2-ZrO2 mean particle size 0.2um)	82%
Filtek Z250 XT	Nano hybrid Universal Composite	A1	3M ESPE St Paul, Minnesota, USA	Resin matrix: Bis-GMA. UDMA, Bis-EMA, PEGDMA, TEGDMA. Filler: silica (20 nm), zirconia/silica clusters (0.1-10 um)	81.8%
		A2			
		A3			

Preparation of the specimens

All molds were placed over a glass slab and then an acetate paper to facilitate the removal of the block without adhering to the underlying surface. Primarily the separate mold is used with the metal spacer leaving only 3 mm for packing Omnichroma. After Omnichroma is packed using a rounded condenser (LM-ARTE CONDENSA; LM-Dental, Parainen, Finland) an acetate paper is placed over the uncured composite and then a glass slab was pressed to extrude any excess. The block is then cured with LED light curing unit (radii plus, SDI Ltd, Victoria, Australia) with an output of 1500 mW/cm2 for 40 seconds on top and bottom surfaces of the specimens.[19,21] Extruded excess material was removed by a gentle pressure of a sharp instrument (LM-ARTE ECCESSO; LM-Dental, Parainen, Finland). The mold is then flipped, metal spacer removed and Omnichroma blocker packed, excess material extruded, and block cured accordingly.

After the separate Omnichroma block is constructed, the blocks are transferred to the adjoined mold and other shades (A1, A2 and A3) are packed adhering to the Omnichroma and pressed with an acetate paper and glass slab to remove excess material. The blocks are then cured for 40 seconds on top and bottom surfaces of the specimens and excess removed.

All separate and adjoined specimens were finished to remove the shiny surface created by the acetate paper. A sequence of four diamond discs [Extra-Coarse, Coarse/Medium, Fine & Extra-Fine] (OptiDisc, Kerr Corporation, USA) was used for finishing and polishing to remove the shiny surface created by the acetate paper.[13–16,19,22,23]

Finishing and polishing was performed by the same operator for 10 seconds each at a speed of 5000 rpm mounted on a low-speed hand piece with mild hand pressure. After that, the specimens were stored in distilled water for 24 hours before color measurements at room temperature.[13,22–24]

Color coordinates measurements

All Specimens were measured by both devices; clinical spectrophotometry and cross-polarized digital photography.

Clinical Spectrophotometry measurement

VITA Easyshade® V (Vita Zahnfabrik, Bad Säckingen, Germany) was used to measure the L*, a*, and b* values of both separate and adjoined blocks.[14,20,22,25] The blocks made of resin composite material were placed on a black matte background with low light reflectance, and the measurements were taken under D65 illumination.

The probe tip of the VITA Easyshade instrument was positioned at a 90-degree angle on the center of the separate block, and on the Omnichroma half of the adjoined block. Before each reading, the device was calibrated using the calibration port aperture according to the manufacturer's instructions. The average shade measurement mode was used, and four separate readings were taken for each base shade. The mean values of L*, a*, and b* were then calculated and recorded in a Microsoft Excel Sheet using Office 365 software.

Standardized cross-polarized digital photography color coordinates measurement

A Cropped frame DSLR camera (Canon EOS 80 D, Canon Inc., Tokyo, Japan), equipped with a Canon EF 100mm f/2.8 L IS USM Macro Lens (Canon Inc., Tokyo, Japan) known for its excellent image quality and macro capabilities, was used in this study. To further enhance the image quality and reduce glare, a Canon polarizing filter (Canon Inc., Tokyo, Japan) was attached to the lens.

To achieve cross polarized photography, an external wireless macro twin flash was used (Meike MT24II-C 2.4; Honkong, China). To control the reflection and polarization of light, custom-made polarizing filter sheets were used. The flash was mounted on the camera lens with a distance of 21 cm and the flash heads positioned perpendicular to the floor and hereby the specimens at a 90 degrees angle.

To ensure stability during photography, a floor tripod was utilized. The camera was positioned in a standardized manner, with the lens perpendicular to the floor and focused on the resin composite blocks. This setup helps to eliminate any potential distortion or movement during the photography process, resulting in clear and accurate images of the resin composite blocks.

The Camera Settings was adjusted in manual mode: Shutter Speed 1/125, ISO 100, and f (16) in RAW format. Lens Magnification 1:1.5 at distance of 21 cm from each composite block. The twin flash was set to manual configuration at 1:1 intensity and a gray reference card (Anwenk, Taiwan) of 18% reflectance was used for white balance calibration.[26–28]

All photos were taken on a black background and a reference was taken on the gray reference card for neutral color reference and then the settings were synced to the rest of the photos. All photos were stored in a SD memory card and transferred to a computer to be analyzed for color match using Adobe Photoshop (Adobe Inc., San Jose, CA).[27]

A grid pattern was superimposed on all images to standardize the area of measurement of each block in the center. The L*, a* and b* coordinates were measured using the Color Sample tool in Adobe Photoshop (Adobe Inc., San Jose, CA). This tool allows for precise measurement of color values in an image. These measurements allow for accurate analysis and comparison of color match between different resin composite blocks. ΔL, Δa and Δb are then calculated through the following equations installed in Microsoft Excel Sheet using Office 365 software:

$$\Delta L = L_{Omnichroma\ adjoined} - L_{Omnichroma\ Separate}$$

$$\Delta a = a_{Omnichroma\ adjoined} - a_{Omnichroma\ Separate}$$

$$\Delta b = b_{Omnichroma\ adjoined} - b_{Omnichroma\ Separate}$$

Statistical Analysis

Numerical data were presented as mean and standard deviation (SD) values. They were explored for normality by checking the data distribution and using Shapiro-Wilk test. Data were normally distributed and were analyzed using One-way ANOVA followed by Tukey's post hoc test. Paired t-test was performed to compare color coordinates of clinical spectrophotometry versus digital photography. The significance level was set at $p \leq 0.05$. Statistical analysis was performed with Graph Pad Prism software version 8.0.1 for Windows.

Results

Color coordinates of Omnichroma measured using clinical spectrophotometry under different adjoined shades:

One-way ANOVA showed statistically significant difference (p value <0.0001) for all color coordinates of Omnichroma when adjoined with different shades measured using clinical spectrophotometry. Tukey's post hoc test showed statistically significant difference in all shades in comparison with the control specimens, on the other hand there were no statistical significance between different shades and one other.

Mean and standard deviation values for the color coordinates measured using clinical spectrophotometry under different adjoined shades are presented in Table (2). Line graphs showing the coordinates measured using clinical spectrophotometry under different adjoined shades are presented in Figure (1), (2) and (3)

Color coordinates of Omnichroma measured using digital photography under different adjoined shades:

One-way ANOVA showed statistically significant difference for all color coordinates of Omnichroma when adjoined with different measured using digital photography. Tukey's post hoc test showed that all shades have a statistically significant difference than the control specimens. Regarding different shades, a statistically significant difference between the shades and each other in both the a* coordinate (A2: 5.83±0.4082 = A3: 5.67±0.5164 > A1: 4.67±0.516) and b* coordinate (A2: 16.83±0.9832 = A3: 17.00±0.00 > A1: 14.50±1.05) while in the L* coordinate only

Table (2): Mean and standard deviation values of color parameters of Omnichroma measured using spectrophotometry and digital photography under different neighboring shades.

Measuring Device	Color parameter	Control	A1	A2	A3	p-value
Spectrophotometry	L	79.2±1.75^{a}	67.7±2.21^{b}	68.1±4.58^{b}	71.9±1.70^{b}	<0.0001*
	A	-3.02±0.55^{a}	-0.65±1.06^{b}	-1.35±0.73^{b}	-1.68±0.34^{b}	<0.0001*
	B	12.12±0.74^{a}	15.30±1.06^{b}	15.80±0.99^{b}	15.90±0.46^{b}	<0.0001*
Digital Photography	L	39.17±1.17^{a}	39.67±1.03^{a}	37.17±1.169^{b}	37.50±1.38^{a}	0.0034*
	A	3.833±0.41^{a}	4.67±0.516^{b}	5.83±0.4082^{cd}	5.67±0.516^{d}	<0.0001*
	B	12.83±0.98^{a}	14.50±1.05^{b}	16.83±0.98^{cd}	17.00±0.00^{d}	<0.0001*

Different superscript letters indicate a statistically significant difference within the same horizontal row *; significant (p ≤ 0.05)

Table (3): Mean and standard deviation values of ΔL, Δa and Δb of Omnichroma measured using digital photography and spectrophotometry under different neighboring shades

Color parameter's difference	Measuring device	Control -A1	Control -A2	Control -A3	p-value
ΔL	Spectrophotometry	-11.53±2.60^{a}	-11.17±4.01^{a}	-7.37±2.22^{a}	0.0585
	Digital Photography	0.50±1.05^{a}	-2.00±1.67^{b}	-1.67±1.97^{ab}	0.0340*
	p-value	<0.0004*	0.0002*	<0.0001*	
Δa	Spectrophotometry	2.37±1.05^{a}	1.67±0.77^{a}	1.33±0.52^{a}	0.1114
	Digital Photography	0.83±0.75^{a}	2.00±0.6325^{b}	1.83±0.75^{ab}	0.0264*
	p-value	0.0298*	0.5516	0.1565	
Δb	Spectrophotometry	3.18±1.38^{a}	3.68±0.99^{a}	3.78±0.83^{a}	0.6045
	Digital Photography	1.67±1.21^{a}	4.00±1.55^{b}	4.17±0.98^{b}	0.006*
	p-value	0.1275	0.5784	0.5915	

Different superscript letters indicate a statistically significant difference within the same horizontal row *; significant (p ≤ 0.05)

A2 shade showed significant difference with other shades (A1: 39.67±1.03 = A3: 37.50±1.38 > A2: 37.17±1.17).

Mean and standard deviation values for the color coordinates measured using clinical spectrophotometry under different adjoined shades are presented in Table (2). Line graphs showing the coordinates measured using cross-polarized digital photography under different adjoined shades are presented in Figure (1), (2) and (3)

Change in color coordinates (ΔL, Δa and Δb) of Omnichroma measured using cross-polarized digital photography and clinical spectrophotometry under different adjoined shades

One-way ANOVA followed by Tukey's post hoc test showed that the ΔL recorded by clinical spectrophotometry shows a decrease in lightness with no statistically significant difference in the Omnichroma when adjoined to different shades (A1: -11.53±2.60 = A2: -11.17±4.01 = A3: -7.37±2.22). ΔL recorded by cross-polarized digital photography shows a decrease in lightness with no statistically significant difference in the Omnichroma when adjoined to A2 and A3 shades (A1: 0.50±1.05 > A2: -2.00±1.67 = A3: -1.67±1.97). Paired t-test showed a statistically significant difference (p value <0.0001) between both devices in measuring ΔL with all shades with mean difference of (11.08±3.19).

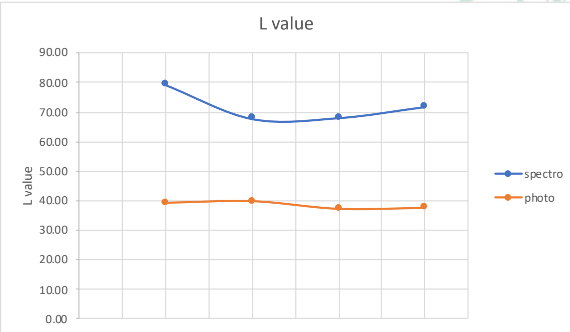

Figure 1: Line Graph showing Lightness value (L*) measured using digital photography and spectrophotometry under different neighboring shades.

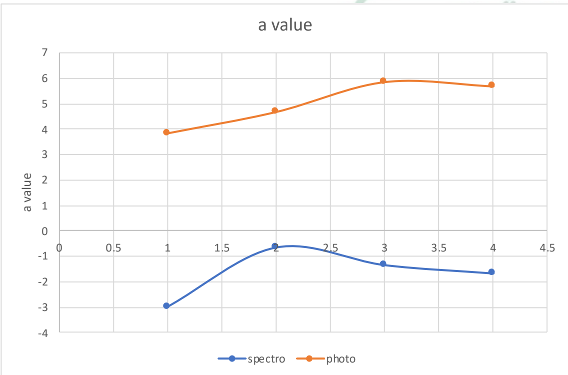

Figure 2: Line Graph showing a value (a*) measured using digital photography and spectrophotometry under different neighboring shades.

Mean and standard deviation values for ΔL of Omnichroma measured using cross-polarized digital photography and clinical spectrophotometry are presented in Table (3).

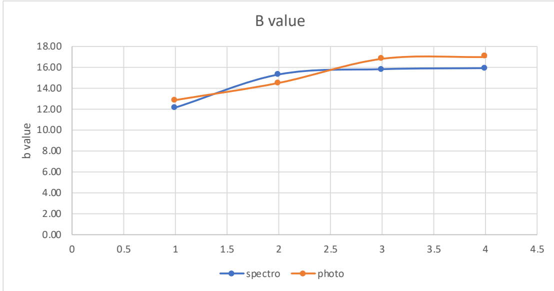

Figure 3: Line Graph showing b value (b*) measured using digital photography and spectrophotometry under different neighboring shades.

One-way ANOVA followed by Tukey's post hoc test showed the following: a positive value denoting an increase of the a* coordinate after the Omnichroma is adjoined to different shades yet the increase wasn't statistically significant between different shades (A1: 2.37±1.05 = A2: 1.67±0.77 = A3: 1.33±0.52) when measured by clinical spectrophotometry. Although the Δa recorded by cross-polarized digital photography is also positive but there was a statistically significant difference between A1 and A2 shades only (A1: 0.83±0.75 < A2: 2.000±0.63 = A3: 1.83±0.75). Paired t-test showed a statistically significant difference (p value < 0.49) between both devices when the Omnichroma was adjoined to A1 with mean difference (-0.23±1.41), and no statistical significance when Omnichroma was adjoined to A2 and A3 shades.

Mean and standard deviation values for Δa of Omnichroma measured using cross-polarized digital photography and clinical spectrophotometry are presented in Table (3). One-way ANOVA followed by Tukey's post hoc test showed that the: Δb is positive denoting an increase of the b* coordinate after the Omnichroma is adjoined to different shades however the increase was not statistically significant between different shades (A1: 3.18±1.38 = A2: 3.68±0.99 = A3: 3.78±0.83) when measured by clinical spectrophotometry. While for Δb recorded by cross-polarized digital photography, it also had a positive value but with statistically significant difference only for A1 compared to other shades (A1: 1.67±1.21 < A2: 4.00±1.55 = A3: 4.17±0.98). Paired t-test showed no statistically significant difference (p value <0.54) between both devices in measuring Δb with mean difference of (-0.27±1.83)

Mean and standard deviation values for Δb of Omnichroma measured using cross-polarized digital photography and clinical spectrophotometry are presented in Table (3).

Discussion

For the dental operator, the pressure to provide aesthetically pleasing results has never been higher. Patients have higher expectations and want their dental restorations to match their natural teeth seamlessly. However, there are still several challenges that persist in shade selection, layering techniques, and clinical expertise.[26,29]

To overcome these challenges, innovations in the material's filler technology are being made. These advancements aim to make the composite resin materials easier to manipulate, blend, and adapt to the remaining tooth structure. The novel universal resin composite, Omnichroma, contains no pigment and depends solely on a smart chromatic technology. The material contains uniform supra-nano spherical fillers 260 nm reflecting red to yellow wavelength in the tooth color space and has a pronounced chameleon effect.[3,15,24]

The translucency of the material increases straight line transmission which is a disadvantage in through and through defects. To overcome such a draw back the manufacturer fabricated an opaquer, Omnichroma blocker, to eliminate the negative effect of the dark background. The lack of sufficient surrounding specially in large esthetic defects could decrease the potential of proper matching of Omnichroma.[30–33]

In this study separate blocks of Omnichroma layered over Omnichroma blocker are used as the control. In this scenario color coordinates are measured with no effect of adjacent shades. The Omnichroma is then adjoined to different shades A1, A2 and A3 to examine the effect of these shades on the color coordinates of the universal composite. The color coordinates that are measured then compared to the control as ΔL, Δa and Δb to examine the expression of its structural color.

Based on the interpretations conducted by Mourouzis et al, distinctions at composite-tooth interface are indistinguishable, which justifies utilizing composite blocks as a simulation of tooth structure to foresee the material's performance clinically.[23]

To detect the inherent color of the resin composites and eliminate the negative effect of the background color, blocks were made in thickness of 4mm.[31,34] The color coordinates are measured using two different instrumental methods clinical spectrophotometry and cross-polarized digital photography.

In our study chroma related color coordinates a* and b* exhibited a shift towards the red-yellow color space. The disparity occurred between both devices in that, clinical spectrophotometry didn't depict a statistically significant difference between the shades. Conversely, cross-polarized digital photography depicted a statistically significant difference between the different shades. The darker the shade the more pronounced the red-yellow structural color is rendered. This could verify that cross-polarized digital photography has a higher sensitivity and may detect smaller color difference.

Considering the previous results, there is a change in the color coordinates of Omnichroma delivering a red-yellow structural color. Yet, only a discrimination was recorded using photography; the darker the shade the more pronounced the structural color.

This red to yellow inherent structural color is further modified by merging with the reflected light of the surrounding in an additive color mixing manner increasing the color assimilation with the surrounding teeth or conventional composites.[20,22,35] Another factor that increases the blending effect of Omnichroma is the change of refractive index of the monomer to closely match the filler's refractive index and to decrease refraction at the filler-matrix interface. A refractive index of 1.47 before polymerization and opaque paste change to a refractive index of 1.52 after polymerization which renders the material more translucent.[20,22,35]

Our results are in accordance with a study conducted by Chen et al, which also recorded an increase of the Omnichroma b* coordinate when adjoined to different shades. On the other hand, the same study had opposing results as the a* coordinates decreased which means that the universal composite was more greenish than reddish.

In our study a statistically significant difference in calculating ΔL between clinical spectrophotometry and cross-polarized digital photography is recorded. On account for a study conducted by Lee et al, it was found that there was a significant difference in lightness measurements between the clinical spectrophotometer and digital cameras.[9,36,37] This difference was attributed to the fact that the clinical spectrophotometer measures diffuse light reflection, which is the light that penetrates the material and re-emerges at the surface. On the other hand, digital cameras measure specular surface reflections, which are the direct reflections of light off the surface. The difference could be also attributed to edge loss effect which occurs with contact spectrophotometers and translucent composites.[13,38]

Within limitations of this in vitro study, an increase in both a* and b* coordinates were recorded instrumentally in all specimens. Indicating a shift towards the red-yellow spectrum that occurred in the Omnichroma resin composite. The null hypothesis tested was rejected as the color coordinates of Omnichroma changed when approximated to different shades, furthermore a difference between both, clinical spectrophotometry, and cross-polarized digital photography, in detecting the change in color coordinates of Omnichroma. Further studies are necessary for investigating whether the change in the color coordinates of Omnichroma resulted in an acceptable color difference with the adjacent shade confirming effective blending.

The morphology of the tooth plays a crucial role in shade match perception. The color of a tooth is not uniform, but rather varies in different areas such as the incisal edge, the body, and the cervical area. Additionally, the shape and size of the tooth can affect how light interacts with the surface, leading to variations in shade appearance. In conclusion, while single shade composite resins have shown promise in simplifying shade matching, further research is necessary to evaluate their predictability and performance with natural teeth. Testing in vivo with a wider range of shades would provide valuable information for clinicians and improve the overall esthetics of dental restorations.

Conclusion

The color coordinates of Omnichroma universal composite change when approximated with different shades. These changes show a pronounced structural color in the red-yellow coordinate, as claimed by the manufacturer. Although clinical spectrophotometry and cross-polarized digital photography detected changes in the color coordinates of Omnichroma, digital photography can discriminate the changes between different shades.

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