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Evaluation of color matching of single-shade resin composite to natural teeth using instrumental and visual techniques

Lina A. Tayyem[1], Faleh A. Sawair[2], Ahmad A. Hamdan[3], Kifah D. Jamani[4], Susan Hattar[5*]

[1]School of Dentistry, The University of Jordan, Amman, 11181 Jordan.
[2,3]Department of Oral Maxillofacial Surgery, Oral Medicine and Periodontology, School of Dentistry, The University of Jordan, Amman, 11181 Jordan.
[4]Department of Prosthodontics, School of Dentistry, The University of Jordan, Amman, 11181 Jordan.
[5]Department of Restorative Dentistry, School of Dentistry, The University of Jordan, Amman, 11181 Jordan.

Corresponding author: Susan Hattar (*Email: s.hattar@ju.edu.jo*)

Abstract

To investigate the blending capacity of a supra-nano filled resin composite with the surrounding natural tooth structure, sixty extracted teeth were randomly divided into two groups. Standardized class V cavities were restored with two types of resin composites: single-shade Omnichroma (experimental group-OMN) and multi-shade Estelite Σ Quick (control group-MS). Teeth were evaluated instrumentally using the Vita Easyshade spectrophotometer, and calculations of color difference CIELAB and CIEDE2000 were performed. Visual assessment was conducted by six calibrated observers using a defined Likert scale from 0 to 4. Significant differences between the MS and OMN groups were noted for different color parameters. The color difference △Eab for the OMN group (14.37) was significantly higher than that of the MS group (10.04) with a p-value < 0.05. Analysis of the overall color difference △E00 revealed no significant difference between the OMN group (△E00=9.85) compared to the MS group (△E00=7.85). In visual assessment, the overall median reading for the MS group was 0.5 compared to 0.92 for the OMN group, with a p-value of 0.01. However, both values were located within the 0-1 category. The supra-nano resin composite (Omnichroma) showed a higher color difference value compared to the multi-shade composite when tested on natural teeth. Nevertheless, the visual results for both composites were within clinically acceptable levels. The single-shade resin composite might be considered a valuable substitute to simplify the restorative procedure in less demanding esthetic clinical situations.

Keywords: Color matching: Instrumental, Resin composite, Visual.

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1. Introduction

A massive development in tooth-colored materials has been widely used due to their superior adhesion properties, excellent mechanical properties, and acceptable cost. Furthermore, the increase in aesthetic concerns and demands of patients, concurrent with the rapid development and advances in adhesive materials, redirected interest to composite materials to be used for direct and indirect restorations, both of which show comparable success rates over time [1].

In daily practice, clinicians face multiple challenges, especially when it revolves around achieving perfect aesthetic outcomes in the anterior zone. Moreover, the inherent polychromatic nature of tooth structure makes the process of shade matching more challenging and complicated. In order to overcome some of these encounters, commercially available composite resins were produced in a variety of shades, translucencies, and opacities [2]. This diversity was produced to replicate the true optical properties of dentin and enamel while mimicking the complexity of tooth structure in what is referred to nowadays as biomimetics [3].

In restorative dentistry, the term chameleon or blending effect describes the ability of a material to acquire a color similar to the surrounding tooth structure [4, 5]. A few years ago, a new resin composite, Omnichroma (Tokuyama Dental, Tokyo, Japan), was produced for the unique purpose of making the shade matching procedure easier on clinicians without going through the process of shade selection or using the conventional layered technique. Omnichroma (OM) was referred to as 'single shade' composite that supposedly would achieve better aesthetic outcomes under any clinical situation. The uniform spacing and arrangement of the spherical particles facilitate light transmission throughout the restoration, thus reflecting the color of the surrounding cavity and improving the blending capacity. As such, the color of the restoration would seem to match its surroundings [6]. Shade-matching techniques are variable, nevertheless, if single shade composites proved to be successful, the clinical matching process could be substantially simplified, and chairside time consequently reduced.

Evaluating color adjustment potential using the CIEDE2000 formula is helpful to assess the blending capacity of different resin composites [7]. Color adjustment potential (CAP) provides a useful guideline for clinical dentistry. It is a term introduced to describe and quantify the interaction of two components, whether perceptual, which is visually assessed, or physical, which is assessed using a color measuring instrument [8]. A study tested the CAP of five composite materials and found that Omnichroma had higher CAP values compared to the other multi-shade composites. They concluded that OM fits in with the surrounding tooth structure, hence the color discrepancy between the material and the surroundings was minimized [6]. Another study performed on extracted teeth revealed that all tested single-shade composite resins exhibited positive color adjustment potential [9].

A study assessing shade matching of Omnichroma was performed on extracted anterior teeth, which were bleached at different intervals for the purpose of assessing the final blending capacity. The analysis demonstrated a perfect match between the tooth structure and OM [10]. These findings support the importance of the structural coloration concept for supra-nano resin composites. A recent study was performed to evaluate the color match of four single-shade resin composites before and after bleaching procedures. The authors concluded that single-shade composites seem to achieve a good color match with the surrounding tooth structure both before and after professional bleaching, revealing their ability to shift color when the surrounding tooth undergoes bleaching [11]. However, the previous findings were opposed by another study, where Omnichroma appeared lighter in shade, however, this change was not maintained 2 weeks postbleaching. The study demonstrated that OM showed readings above the perceivable threshold value of 3.3 [12]. These thresholds can serve as a quality control tool to guide the selection of dental materials, evaluate their clinical performance, and interpret visual and instrumental findings in clinical dentistry, dental research [13].

Color holds significant importance in dentistry as a key aesthetic factor. Various elements influence the color of composite resins, among other properties, translucency was positively correlated with the material color-matching effect [14, 15]. Another important factor that interferes with the final color matching is the surrounding tooth structure, which is reflected by the impact of size and depth of the restored cavity [5]. A study performed on both acrylic and natural teeth testing Omnichroma revealed that the blending capacity decreased with increased depth of the cavities [16]. Furthermore, color interactions are also related to layering, which is the very essence of tooth anatomy [17].

Recently, it was found that shade matching can be attained by increasing the material's translucency or via structural color phenomenon [14, 18-22]. Translucent resin-based materials allow the underlying substrate color to strongly affect the restoration's final shade, resulting in enhanced blended appearance [4, 14, 19]. A study comparing translucency adjustment potential for OM confirmed its positive blending effect [19]. Concerning structural coloration, it mainly depends on the size and distribution of fillers. Accordingly, the presence of supra-nano fillers can possibly improve blending capacity by displaying a spectrum of reduction in brightness and chromatic value [23].

Color appearance of dental restorations can be affected by the surrounding colors [14, 24]. The concept of blending, also known as color assimilation, color induction, Von Bezold color blending effect, refers to the reduction in perceived color difference when viewing the colors in juxtaposition compared to their isolated observation. Quantifying the blending potential of dental materials might provide useful clinical information for dental professionals [5]. A recent study testing three different types of composites on bi-layered acrylic teeth showed that both Omnichroma and TPH Spectra showed excellent matching and lower $\Delta E00$ values, especially for lighter shades [15].

Another study examined the shade matching ability of composite resins with different filler morphologies and light transmittance characteristics. The authors concluded that the novel supra-nano filled composite with structural coloration ability displayed better matching and provided a facilitated procedure in restorative dentistry Chen et al. [25]. De Abreu et al. [26] performed a study evaluating the color matching ability of multi-shade versus single-shade composite resins placed in acrylic teeth. The photographic and visual assessment showed a higher matching ability for the multi-shade composite compared to the single-shade composite, with no significant difference. The study revealed promising results regarding universal composites, which might reduce clinical errors and simplify the shade matching process [26].

The majority of the previous studies were conducted on acrylic teeth or simulated cavities. One study using human extracted teeth demonstrated that composites containing spherical nano fillers developed structural color phenomena and improved the color adjustment potential of the restorations to various shades of teeth. The study involved a photographic assessment and revealed that Omnichroma exhibited significantly lower color difference values ΔE00 compared to the other tested composites [21].

On the other hand, clinical trials regarding this novel composite are scarce and validated only in the short term. One randomized split-mouth trial testing the color matching of Omnichroma after 6-12 months concluded that its clinical performance was comparable to nanohybrid composite [27]. In another clinical study, anterior restorations using Omnichroma composite were evaluated instrumentally. The authors concluded that Omnichroma showed poor clinical color matching in anterior teeth. Color changes (ΔE) ranged from 2.01- 8.54, which is higher than the perceivable threshold. In addition, the visual evaluations were overall stated as unacceptable by dental students, yet considered highly acceptable by the patients [28].

The aim of this study was to investigate whether there is a difference in color matching potential between single-shade composite (Omnichroma) and multi-shade composite applied by layering techniques. The main objective was to measure the color difference between the composite material and the tooth using both instrumental and visual methods. The null hypothesis states that there is no difference between the color matching capacity of single-shade composite compared to multi-shade resin composite.

2. Materials and Methods

Teeth gathered were extracted for periodontal or orthodontic reasons and collected from the Surgery Specialty Clinics. Two commercial composite resin materials were evaluated in this study (Table 1): single-shade resin composite Omnichroma (Tokuyama Dental, Japan) and universal multi-shade resin composite (Estelite Σ Quick-ESQ) (Tokuyama Dental, Japan).

Table 1.
The composition of experimental (Omnichroma) and the control (Estelite Σ Quick) resin composites.

<table>
<tr><th>Material</th><th>Manufacturer</th><th>Filler weight</th><th>Base resin</th><th>Filler size</th><th>Filler type</th></tr>
<tr><td rowspan="2">Omnichroma</td><td>Tokuyama Dental,</td><td rowspan="2">79%</td><td rowspan="2">UDMA, TEGDMA</td><td rowspan="2">uniform-sized supra-nano spherical filler (SiO2-ZrO2 260 nm), round-shaped composite filler (containing 260 nm spherical SiO2-ZrO2)</td><td>Supra</td></tr>
<tr><td>Tokyo, Japan</td><td>nano filled</td></tr>
<tr><td rowspan="2">Estelite Σ Quick</td><td>Tokuyama Dental,</td><td rowspan="2">82%</td><td rowspan="2">UDMA, TEGDMA</td><td>uniform-sized supra-nano spherical filler (SiO2-ZrO2,</td><td rowspan="2">Nano filled</td></tr>
<tr><td>Tokyo, Japan</td><td>SiO2-TiO2 100–300 nm (average 200 nm), round-shaped composite filler (100–300 nm) (average 200 nm), spherical SiO2-ZrO2)</td></tr>
</table>

TEGDMA, triethyleneglycol dimethacrylate; UDMA, urethane dimethacrylate; Bis-GMA, bisphenol-A-glycidyl methacrylate.

The study involved two assessment methods. The first consisted of an instrumental evaluation of the shade matching using an intraoral spectrophotometer. The second consisted of a visual assessment in which clinical observers evaluated and rated the shade matching.

2.1. Sample Preparation

Sixty human teeth (30 premolars, 30 molars) were included; the sample size was based on previous studies [10], AlHabdan et al. [12], and Kobayashi et al. [21]. Decayed and discolored teeth were excluded from the study. Teeth were polished using a rubber cup and pumice prior to their use. A cylindrical silicon index was fabricated for each tooth, placed perpendicularly to standardize the observational view. Each tooth was stored in a single container, immersed in distilled water and stored in the freezer at -10°C for 24 hours prior to the baseline color measurement. This procedure was followed to avoid changes in the optical properties of the teeth [29]. Standardized class V cavity preparations with 90-degree cavo-surface margins without any bevel were created by a single operator at the cervical third of the buccal surface of the tooth. The cavity design was 4 mm in width, 2mm incisogingival, and 2mm in depth, performed using a high-speed carbide bur (No. 245). The cavities were prepared under magnification and a periodontal probe (Michigan O probe) was used to confirm the depth and width of the cavities.

Following the preparation, all cavities were water cleaned and air dried with the triple air syringe. Selective etch approach was performed, phosphoric acid 35% (Ultra-etch, Ultradent Inc.) was applied 30 sec on the enamel, washed for 30 sec and air dried for 2 seconds. A self-etch seventh generation bonding agent was applied according to the manufacturer's instructions (Bond Force, Tokuyama Dental, Tokyo, Japan), using a micro brush, air thinned then light cured for 20 second using an LED light cure unit (Bluephase II, Ivoclar Vivadent).

Teeth were divided randomly into two groups, each group consisted of 30 teeth. Group OMN was the experimental group restored with Omnichroma resin composite. The second group MS was the control group restored with the multi-shade Estelite Σ Quick (ESQ).

The composite was placed in a single increment for the Omnichroma composite and in two layers for the ESQ composite (1mm dentine shade and 1mm enamel shade), then polymerized according to the manufacturer's instructions using an LED curing lamp. A glycerin layer was applied to prevent formation of air inhibited layer with a total curing of 40 seconds. The output intensity of the light cure unit was monitored using the radiometer (Blue phase meter II, Ivoclar Vivadent).

Subsequently, restorations were completed, and the surface was flattened for ease of measurement using a sequence of diamond finishing burs. This was followed by the polishing phase for 40 seconds under light pressure utilizing a rubber polisher point (Enhance finishing system, Dentsply, Sirona). The specimens were stored in distilled water for 48 hours for rehydration purposes before initiating the color measurements.

2.2. Instrumental Evaluation

This part consisted of a spectrophotometric analysis using VITA Easyshade (VITA Easyshade V, VITA ZahnFabrik, Sackingen, Germany) which is an intraoral spectrophotometer with a 5-mm probe tip. The device is designed with a diffusion illumination mode, a 45-degree viewing geometry angle, including specular components [30].

Two color measurements were consequently recorded, whereas the reflection values of the tooth and the restoration were gathered. The first reading represented the restoration's color values, which were taken by placing the measuring tip of the spectrophotometer perpendicular to the center of the restoration and 1 mm away from the cavosurface margin. The second reading represented the tooth color values, which were taken by placing the measuring tip incisal to the filling and 1 mm away from the cavosurface margin, situating the center of the probe 3 mm away from the center of the restoration. Two readings were taken for each point and averaged as a single data point. The measurements were taken directly after the removal of teeth from the distilled water while being placed on a neutral grey background. The device was calibrated after each registered measurement.

In order to evaluate the color and color difference between the tooth and restoration, color values were converted to CIELab color coordinates defined by the International Commission of illumination (CIE) by the spectrophotometer. The color difference were calculated using the two standard formulas. The first was the CIELAB formula, the second was CIEDE2000 calculated using the standard equations [31]. Where $\Delta L00$, $\Delta C00$, and $\Delta H00$ are the differences in lightness, chroma, and hue, respectively, for each pair of points. An online excel spread sheet was used for the calculation of $\Delta E00$ [32].

2.3. Visual Evaluation

Visual color evaluations were performed by six dental professionals. The evaluators: 3 prosthodontists and 3 postgraduate students who demonstrated superior color discrimination competency according to ISO/TR 28642:2016 [33]. The color discrimination competency was performed by using 12 pairs of shade tabs from the Vita 3D-Master, placed in a viewing booth with all external lights turned off during assessment. All the tabs were randomly placed, and observers were asked to match the tabs. The observers with a higher discrimination ability would score at least 60%.

Specimens were evaluated blindly under D65 illuminant with color temperature 6500 K using a 0/45 degrees viewing geometry in a viewing booth, with room light turned off, by the six calibrated observers. The color difference between the tooth and restorations was graded following a defined Likert scale from 0 to 4 where 0 means exact match/no color difference; 1: very good match/small difference; 2: not so good matching/hardly acceptable; 3: obvious mismatch, 4: huge (pronounced mismatch) and the observers were familiarized with the scale prior to the evaluation according to ISO/TR 28642:2016 technical report [33]. The evaluators were asked to rank the shade match and were given 25 seconds to assess the specimens. After evaluation of each tooth, the observers were allowed to look at a neutral background to avoid eye fatigue. After gathering readings, the average for the students, average for the specialists, average for each shade, number of readings for each grade, perceptibility, and acceptability percentages were noted.

The frequency level of perceived/accepted color differences was determined and recorded according to Paravina et al. [13]. The perceptibility percentage (PP) question "Can you see a difference in color between the two specimens, in other words, the tooth and the restoration?" This would be equal to all grades except grade zero in our Likert scale. The acceptability percentage (AP) question: "Would you consider this difference in color acceptable in a patient's mouth?", which is equal to grade 1 in our Likert scale. The psychometric function is then simply the percentage of "yes" responses as a function of specimen color difference; 50% "yes" responses are considered as the threshold level. The responses of each pair of specimens were analyzed and percentages were calculated according to the following formulas. PT was calculated as follows:

$$\text{Perceptibility/Acceptibility }\% = \frac{S_i}{N_i}$$

Where Si was the number of observers who answered "yes" to PT or AT question and Ni was the total number of observers [34].

2.4. Statistical Analysis

Statistical analysis was performed using SPSS for Windows release 16.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics were generated and normality of the measurements Delta L, Delta a, Delta b, Delta Eab, Delta E00, DL00, DC00, DH00, TPS and mean scores for specialist and student evaluation were tested by numerical (skewness, kurtosis, z values, and Shapiro-Wilk test) and visual outputs (Histograms, normal Q-Q plots and Box plots). These methods showed that these values were not normally distributed and, therefore, Mann–Whitney U test was used to compare median scores between the different groups. The significance level was stated as $P < 0.05$.

3. Results

3.1. Instrumental Evaluation

Differences in median values of color coordinates between the tooth and the restorations: $\triangle L$, $\triangle a$, $\triangle b$ for the two groups, OMN (experimental) and MS (control), are summarized in Table 2. The final overall color difference $\triangle E_{ab}$ was also calculated. These results were subdivided according to each shade group (shade A, shade B and shade C).

Results showed that the differences in color parameters $\triangle L$, $\triangle a$, $\triangle b$ were statistically significant for shade groups A and B with lower difference values for the multi-shade control group (MS) compared to the single-shade experimental group (OMN). However, shade group C did not reveal any significant differences in either of the measured parameters. Nevertheless, when the whole sample was compared regardless of the shade group, significant differences in values were noted in all $\triangle L$, $\triangle a$, $\triangle b$. Mann-Whitney U test revealed that the color difference between the tooth and the restoration $\triangle E_{ab}$ for the OMN group was significantly higher (14.37) compared to (10.04) recorded for the MS group as presented in Table 2. The range of color difference between the tooth and the restoration ($\triangle E_{ab}$) for group MS was 1.5-36.3 and for group OMN was 2.8-26.9.

Table 2.
Median values of $\triangle L$, $\triangle a$, $\triangle b$, and $\triangle Eab$ for OMN and MS groups.

Shade	**Groups**	**N**	**$\triangle L$**		**$\triangle a$**		**$\triangle b$**		**$\triangle E_{ab}$**	
			Median	**P value**	**Median**	**P value**	**Median**	**P value**	**Median**	**P value**
Group A	MS	12	-1.68	0.017	-0.65	< 0.001	-4.9	0.01	6.75	0.054
	OMN	8	-11.55		2.88		2.38		13.06	
Group B	MS	12	-3.98	0.007	-0.8	< 0.001	-5.45	0.014	11.1	0.074
	OMN	19	-13		3.05		1		15.49	
Group C	MS	6	-13.25	0.61	1.55	0.2	-2.38	0.3	14.05	0.44
	OMN	3	-9.3		3		2.5		9.8	
All	MS	30	-5.85	0.002	-0.53	< 0.001	-5.13	< 0.001	10.04	0.023
	OMN	30	-12.32		3.03		1.38		14.37	

The difference in color parameters between the tooth and the restorations $\triangle L_{00}$, $\triangle C_{00}$, $\triangle H_{00}$, $\triangle E_{00}$ are summarized in Table 3. Regarding the parameters $\triangle L_{00}$, $\triangle C_{00}$, $\triangle H_{00}$, the data revealed a significant difference between the two groups MS and OMN for shades A and B, while shade C revealed a significant difference in $\triangle H_{00}$ only.

Table 3.
Median values of DeltaL$_{00}$, Delta C$_{00}$, Delta H$_{00}$, and Delta E$_{00}$ values for OMN and MS groups.

Shade	**Group**	**N**	**$\triangle H_{00}$**		**$\triangle L_{00}$**		**$\triangle C_{00}$**		**$\triangle E_{00}$**	
			Median	**P value**	**Median**	**P value**	**Median**	**P value**	**Median**	**P value**
A	MS	12	0.57	**< 0.001**	-1.21	**0.017**	-2.41	**0.011**	6.75	0.32
	OMN	8	-2.93		-8.22		1.09		9.04	
B	MS	12	0.62	**< 0.001**	-2.88	**0.011**	-2.79	**0.015**	11.10	0.75
	OMN	19	-3.34		-9.12		0.37		10.77	
C	MS	6	-1.11	**0.07**	-10.67	0.44	-1.05	0.44	14.05	0.07
	OMN	3	-3.36		-6.60		0.98		7.45	
All	MS	30	0.42	**< 0.001**	-4.11	**0.004**	-2.51	**< 0.001**	7.85	0.70
	OMN	30	-3.16		-8.56		0.55		9.85	

Source: Bold P value indicates significant difference between OMN and MS.

Analysis of the overall color difference ($\triangle E_{00}$) demonstrated that the control group MS had a color difference $\triangle E_{00}$= 7.85 while the experimental group OMN had a color difference $\triangle E_{00}$= 9.85 with no significant difference. In addition, evaluation of the different shade subgroups did not reveal a significant color difference between group OMN and MS. The range of color difference between the tooth and the restoration ($\triangle E_{00}$) for group MS was 0.75-29.9 and for group OMN was between 2.3-21.1.

3.2. Visual Evaluation

Two categories of observers evaluated the shade matching of composite restorations to the natural tooth (3 specialists and 3 postgraduate students). The visual ratings in Table 4 show an overall reading of color matching for the MS group equal to 0.5 compared to 0.92 for the OMN group with a significant difference noted (*P* =0.01). The OMN group grade approached 1, which denotes very good match rather than an exact match. Nevertheless, both values were located within the 0-1 category, which represents 0: exact match/no color difference; 1: very good match/small difference. In other terms, they fall between the perceptibility and acceptability color thresholds meaning there is a difference in the shade of the restoration compared to the adjacent tooth, yet the matching is still considered acceptable. The results also showed that the only shade group that demonstrated a significant difference of visual readings was shade B with a P value of 0.001, and no significant difference was seen in the other two shade groups A and B.

Table 4.
Median values of visual readings.

Shade	Group	N	Specialist		Student		All	
			Median	P value	Median	P value	Median	P value
A	MS	12	0.67	0.78	0.33	0.36	0.67	0.56
	OMN	8	0.67		0.67		0.75	
B	MS	12	0.33	**0.009**	0.33	**0.001**	0.33	**0.001**
	OMN	19	1.00		1.00		1.17	
C	MS	6	1.33	0.79	0.83	0.22	0.92	1.00
	OMN	3	1.00		0.33		0.66	
All	MS	30	0.67	0.06	0.33	**0.005**	0.50	**0.01**
	OMN	30	1.00		1.00		0.92	

Source: Bold P value indicates significant difference between OMN and MS.

As shown in Figure 1, the percentage of readings for Grade 0 (prefect match) was around 37% for OMN compared to 57% for MS group, whereas the percentage of readings for Grade 1 (very good match) was around 36% for OMN compared to 26% for MS group. When the percentages of readings were assessed according to the evaluator (student, specialist), the data showed similarity in the overall ratings. As previously mentioned, most of the readings were within these two grades with a higher percentage of Grade 0 for the MS compared to the OMN group.

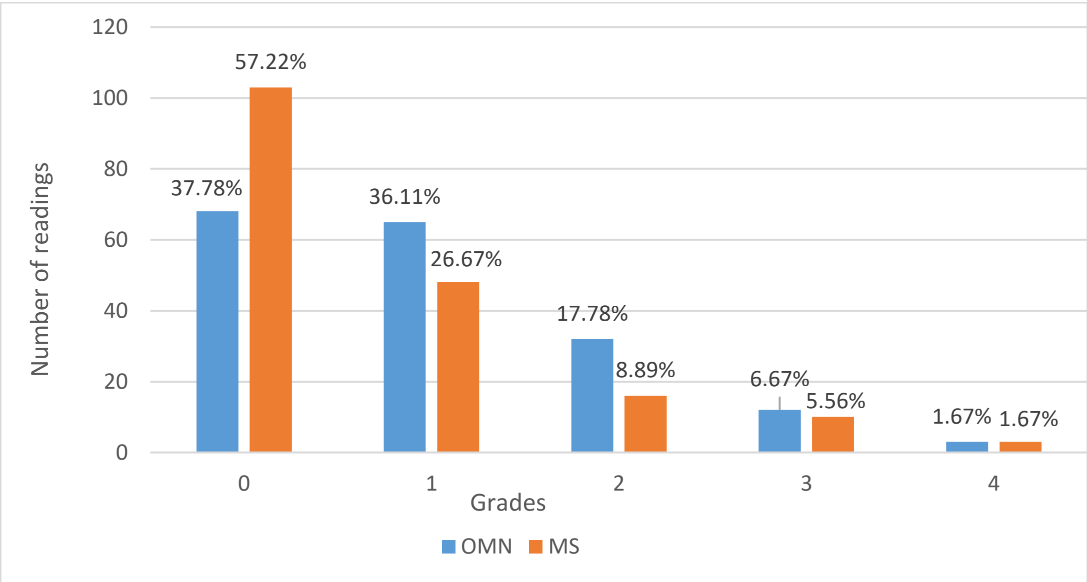

Figure 1.
Number and percentages of readings for each grade for the groups OMN and MS (all Observers).

Table 5 demonstrates the perceptibility and acceptability percentages calculated as per the previously explained equation. Perceptibility percentage reveals the percentage of readings in which the observer denotes a perceptible difference in shade between the tooth and restoration. While the acceptability percentage represents the percentage of readings in which the observer denotes a perceptible difference in shade, yet acceptable matching. With all observers' results considered, Group OMN showed a higher perceptibility percentage of around 62% compared to 50% for the MS group. Whereas Group OMN showed a lower acceptability percentage 58% compared to 62% for group MS. Percentages divided per observer category, whether student or specialist, are also shown in Table 5 with similar outcomes.

Table 5.
The Percentages of Perceptibility Pt and Acceptability at Among Observers.

Observer	Acceptability /Perceptibility percentages	Experimental OMN group	Control MS Group
All observers	PT	62%	43%
	AT	58%	62%
Specialists	PT	63%	48%
	AT	49%	53%
Students	PT	62%	38%
	AT	66%	74%

4. Discussion

Matching the shade of teeth is without doubt one of the most challenging tasks in dentistry. It is associated with the acceptance of the restoration both by professionals and by patients. Nevertheless, relying solely on a resin material to mimic the polychromatic structure of teeth sometimes leads to unpredictable aesthetic outcomes. Furthermore, it was shown that color matching is a complex process based on many variables such as surrounding tooth color, material properties, translucency as well as cavity depth [19]. The null hypothesis of the present study was rejected since there was statistically significant differences in instrumental and visual color readings between single shade composite (Omnichroma) compared to multi-shade resin composite.

A variety of evaluations performed with intraoral spectrophotometers demonstrated that the shade matching ability is indeed composite and shade dependent [15]. Instrumental analysis was performed in our study in conjunction with visual analysis. It has been shown that there are some limitations to measuring tooth color using only instrumental devices. Human teeth are small and curved, which can lead to poor color readings because a considerable part of the light that strikes the tooth surface is lost. Consequently, it is recommended that the instrumental determination of color should be accompanied by experienced human visual perception to achieve a better color assessment [35]. The instrumental color difference values in the present study denoted a statistically significant difference for Delta Eab but not for Delta E00. On the other hand, the visual findings revealed acceptable matching results for both experimental and control samples. Most of the score levels were between 0 and 1, reflecting an acceptable match. Comparable results were shown in a recent study also conducted on extracted human teeth. Instrumental analysis showed that multi-shade resins possessed better color correspondence compared to single-shade shade. Nevertheless, in the visual evaluation, all groups demonstrated acceptable color matching with single-shade composite resins showing better matching values than the multi-shade resin [36].

Interpretation of color differences has been documented through the use of perceptibility and acceptability thresholds for the purpose of ensuring the predictability of the final aesthetic outcome. When reviewing the literature, thresholds in dentistry have been defined by many studies, with a variety of suggested values. Most of the literature refers to the 50:50 perceptibility threshold as a Delta E00 equal 0.8, whereas the 50:50 acceptability threshold is equal or below 1.8 [13, 34]. The findings of the instrumental analysis showed that both Omnichroma and multi-shade ESQ had comparable overall DeltaE00 values, yet above the recommended thresholds and similar to the results of a recent study, Cruz da Silva et al. [36]. From another perspective, a numerically small ΔE value does not necessarily correspond to the best match since the color difference may still be clinically acceptable, which was disclosed in the visual assessment outcomes. Additionally, the fact that the polychromatic nature and translucency of teeth was variable might have played an essential role in the results acquired. It is important to note that the color of composite resin depends on its surroundings, and natural teeth constitute a complex, multilayered environment. Another matching influential factor is the age of teeth, since ageing is associated with darkening of tooth shades [37]. Teeth samples used in the current study had a variable distribution of shade and age with a different number of teeth for each shade group, these factors might have played a substantial role in the results obtained. Moreover, it appears that Omnichroma produces better matching with lighter shades of teeth [15]. Our samples were mostly composed of light shades and very few numbers presenting darker shades.

CIELAB and CIEDE2000 formulas are both recommended by the International Commission on Illumination [32] for evaluating color differences. Our results demonstrated high color difference Delta Eab values for both groups, however, the Delta E00 revealed lower values with no significant difference. Many studies still employ the CIELAB formula, nevertheless, the CIEDE2000 has been found to better correlate with visual findings [31]. A recent study performed on simulated clinical cavities measured the matching ability of resin composites similar to the ones used in our work [25]. The authors concluded that structural color technology might provide benefits for shade matching, since the study showed lower color difference values for Omnichroma. Comparable outcomes were noted in a study demonstrating that Omnichroma exhibited the highest adjustment potential for all color dimensions [19]. Their values were measured using a non-contact spectroradiometer and appeared lower than the data presented in our work. When comparing the results with previous studies, the authors realized that using a contact spectrophotometer might have contributed to the high Delta E values recorded, for most of the studies with small Delta E values were conducted using either a non-contacting spectroradiometer or relied on photography for their measurement [10, 26]. In fact, it has been shown that the use of a non-contacting spectroradiometer gives more accurate results than contact devices [38]. This is attributed to the fact that a contacting spectrophotometer with a relatively wide probe could be affected by the site movement between one reading and the other. Another factor that might have influenced our results is the design of the cavity being smaller than the probe of the device. In the study of Iyer et al. [15], the authors designed a cavity similar to the shape of the VITA Easy shade probe.

Few studies evaluating the structural coloration were conducted on natural teeth [9, 10, 36]. One study performed on human incisors aimed at exploring the color reproduction potential of this newly developed composite on the cervical area of teeth [21]. The spectral reflectance and color difference were measured using a camera and results showed a significantly lower delta E00 for Omnichroma compared to other multi-shade composites, indicating a superior color adjustment potential. However, the higher reported ΔE values for the multi-shade composites might have been the result of using only a single shade to mimic the colors of all tested teeth.

Visual Assessments for composite blending have been generally used and considered as practical, realistic, and more clinically significant, especially when evaluators with superior competence in the field of esthetic dentistry are involved. Nevertheless, using instruments to assess color matching has the advantage of reducing imperfections and inconsistencies that are presented in visual matching assessments [35]. In some studies, the visual evaluations of color differences performed by trained specialists or students did not correspond to the instrumental analysis [6]. While other studies showed good correlation between both evaluation methods [8, 15, 26]. An important factor when using both methods is to ensure that the observed and measured area are exactly the same since discrepancies can influence the quality of findings [13]. Also, the agreement between both methods seems higher when the assessment is performed by experienced dentists [39, 40]. There is no specific answer whether to use visual or instrumental; however, whenever possible, use both as they complement each other, since the inter and intra-rater reliability is variable among studies, Igiel et al. [41]. The current visual assessment was far more promising than the instrumental, although the multi-shade group revealed a score closer to the perfect match. The different polychromatic nature of the teeth samples might explain the significant color differences noticed in the instrumental readings. Consensus is lacking whether the use of natural teeth is more informative, nonetheless, their use constitutes a valuable method for checking optical properties of dental materials while reflecting their true clinical performance.

Color parameters were also measured and compared separately to investigate whether any of the former variables had a significant effect on the color differences. No significant difference was noted between the OMN and MS groups. In a study done by Kobayashi et al. [21], ΔL and ΔH values which denote the difference in value and hue parameters, were significantly lower for Omnichroma compared to the other types of composites. The authors concluded that the size and uniform spherical shape of fillers contained within the matrix contribute to the improvement of color adjustment potential and play an important role in the structural coloration.

Based on the variety of single shade resin composites and research protocols, the literature shows contradictory results. A former study based on photographic analysis and visual assessment was performed by calibrated observers with a strong correlation between the two methods [26]. Their results showed that Omnichroma possessed the highest ΔE values and visual scores. While another study investigated the visual color adjustment potential by 3 observers and found that Omnichroma had the most pronounced color adjusting potential, which was also correlated to their instrumental evaluation [6].

Reviewing our data, the visual analysis gave an indication of having a high acceptability percentage for both types of composites. The higher the acceptability percentage the better the match. The following conclusion may be drawn: Omnichroma possesses different optical behavior compared to multi-shade composite [20] It shows promising results to blend with tooth structure, nonetheless, multi-shade composites represent the cornerstone for highly esthetic restorative procedures. The current results conform with the other studies Iyer, et al. [15] and De Abreu, et al. [26], which indicated that single-shade composites exhibit lesser color matching than multi-shade composites, restricting their clinical use to situations with moderate esthetic demands.

The blending of the composite to the tooth structure is affected by multiple factors [4, 16]. Omnichroma has optical properties different than other studied composites and reveals high translucency at different thicknesses [20]. One limitation of our study is the low sample number and unequal distribution of shades for each group, which is preferred to be 50 pairs for each shade group [34]. This might have led to the presence of outliers resulting in a distribution that was not normal. According to previous studies, mismatch was more noted in darker tooth shades [4, 5, 25]. However, comparing the effect of tooth shade on the end outcome was not plausible, since the shade groups were not homogeneously distributed.

Further studies with a larger sample size and with the use of a non-contacting device could be performed to overcome some limitations. In addition, future research is essential to analyze various other parameters, such as translucency parameters, optical properties, color stability, effect of cavity depth, and nature of tooth shades on the blending capacity of Omnichroma along with other similar single shade resin composite materials, might prove to be beneficial. Moreover, performing clinical studies to demonstrate the effectiveness of color blending in vivo is mandatory.

5. Conclusion

Within the limitations of the study, the supra-nano single-shade resin composite (Omnichroma) showed a higher color difference value compared to multi-shade composite when measured instrumentally; nevertheless, the visual results were considered clinically acceptable. The present in vitro study demonstrated that single-shade composite resins exhibit acceptable color adjustment potential to natural teeth. The findings of this study can partially fill the data gap on the use of single-shade composites in the restoration of human teeth with various shades.

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