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Dental Color Matching: A Comparison between Visual and Digital Shade Selection Repeatability in the Anterior and Posterior Region: A Clinical Study

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Abstract: The clinical study aimed to evaluate the repeatability of the Intraoral Scanner (IOS) in terms of dental shade selection in comparison to the visual method and to find if the difference between these two methods is clinically acceptable. As well as to assess the impact of tooth position on the repeatability of the IOS in shade selection. Two experienced raters have selected the shades of 38 right maxillary incisors, canines, and molars in 38 patients on two different days under the same clinical conditions using both the visual method and the trio's intraoral scanner. Vita toothguide 3D-master was used as the shade guide reference for both methods. Delta E (ΔE) was calculated to assess the repeatability of each technique and to evaluate the difference in color matching between each observer and the IOS. Data were analyzed using IBM SPSS Statistics for Windows and the level of significance was set at 5%. Results of repeatability assessment between day 1 and day 2 for the visual method and the intraoral scanner were higher in the incisor region but lower in the canine and molar region for the IOS compared to the visual method. However, this difference is not statistically significant in all regions ($p>0.05$). The color difference between the visual technique and the IOS was significantly lower than the clinical acceptability threshold, except between the second rater and intraoral scanner on day 2 for the molar region. Within the intraoral scanner, the repeatability agreement rate was significantly greater for the central, compared to the canine and molar teeth. The IOS is a reliable instrument for color shade selection compared to the visual method, especially in the anterior region; however, tooth position had an impact on its repeatability.

Keywords: Dental Shade Matching, Delta E, Intraoral Scanner, Repeatability, Visual Shade Selection

Introduction

Accurate shade measurement and shade communication are one of the most challenging steps required of practitioners performing dental restorative procedures (Hardan *et al*., 2022). Proper tooth color determination plays an important role in attaining a good esthetic outcome (Sampaio *et al*., 2019).

In the literature, no clear consensus on one standard way for tooth shade determination can be found. Only two main methods exist to evaluate color in dentistry, which is the visual and the instrumental methods (Sampaio *et al*., 2019; Haddad *et al*., 2009).

Visual tooth color determination is the standard and the most generally used technique due to its simplicity and low cost (Sirintawat *et al*., 2021). It consists of matching the patient's tooth color with that of the dental shade guide; where the practitioner selects the color that seems most suitable based on his clinical criteria (Reyes *et al*., 2019).

However, the color determination accomplished by the visual method depends on several human and environmental factors. In fact, numerous aspects must be considered, including the observer's age, gender, experience, color perception, and eye fatigue, as well as location and degree of light intensity (Sirintawat *et al*., 2021).

The second method includes a variety of electronic color assessment equipment such as spectrophotometers, colorimeters, and digital cameras (Reyes *et al*., 2019). This technique is designed to overcome the shortcomings of the visual method. Spectrophotometers are frequently used as a reference device in several updated comparative studies. This device, however, is not usually available in daily dental practice due to its high cost (Sirintawat *et al*., 2021).

The use of intraoral scanners is one of the most recent developments in digital prosthodontics. Intraoral Scanners (IOS)s are chairside devices that are used to capture a direct optical impression of a patient's teeth and are often used as an alternative to conventional impression methods (Moussaoui *et al*., 2018). The newly designed intraoral scanner has added a dental shade determination option comprised in its software settings allowing the clinician to select the shade.

Because it combines several functions in one digital instrument, this innovation will be tremendously helpful to the dentist, dental technician, and patient, saving time and money (Moussaoui *et al*., 2018). Nevertheless, in order to be used for shade dental measuring, an instrument must be accurate, repeatable, and reliable (Moussaoui *et al*., 2018).

The accuracy of a testing instrument is determined by comparing it to a gold standard reference device. The repeatability of a measuring instrument, on the other hand, is measured by comparing repeated measures of the same specimen (Moussaoui *et al*., 2018; Khashayar *et al*., 2014). While interrater agreement determines reproducibility (Moussaoui *et al*., 2018).

Several pieces of research have been carried out to evaluate the accuracy and repeatability of intraoral scanners used for shade matching. However, the findings and conclusions differed greatly (Akl *et al*., 2022). The limited number of published studies regarding the intraoral scanner shade selection, the heterogeneity of the protocols, and the discrepancy in the results render the use of the IOS in dental color matching controversial.

Moreover, none of these studies compared the effect of the tooth position on the repeatability of the IOS according to the 3-color dimension, and fewer compared the color difference between the visual and IOS to see if this difference would be perceptible or clinically acceptable.

It is important to note that ΔE is of clinical significance in dentistry when it is used to assess the perceptibility and acceptability of a difference between two colors (Khashayar *et al*., 2014). Perceptibility corresponds to the change in color that can be visually detected and acceptability corresponds to whether the detected color difference is acceptable when it comes to aesthetics (Khashayar *et al*., 2014; Hardan *et al*., 2022). To overcome such limitations, the objectives of this study were to evaluate the repeatability of the IOS compared to the visual method in the anterior and posterior regions. It assessed if there was a perceptible difference between the two methods in the anterior and the posterior regions. A secondary objective was to evaluate the impact of tooth position on the repeatability of the IOS for each color dimension.

Materials and Methods

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments. This study was reviewed and approved by the Saint Joseph University research ethics committee, Beirut, Lebanon (ref: USJ-2022-207).

The initial study sample comprised 45 dental students aged between 20 and 28 years having sound and vital right maxillary central incisor, canine, and first molar. 7 students dropped out of the study and the total number of subjects that underwent the experiment was 38 patients. Therefore, shades of 38 centrals, 38 canines, and 38 molars were evaluated by using the conventional visual method and the digital intraoral scanner method on 38 participants. All the participants received verbal and written information and signed an informed consent form before inclusion. They were given professional oral hygiene instructions prior to the procedure. Exclusion criteria consisted of any previous restorative or bleaching procedures, presence of congenital or acquired tooth color changes (demineralization, fluorosis, enamel hypoplasia), or any periodontal problem (gingivitis, periodontitis).

Patients were seated in the same dental chairs at the clinic, reclined at an angle of 45°C to the floor. Before any measurement procedure, the teeth were checked and cleaning was done in the presence of any plaque or discoloration.

For the visual method, two experienced clinicians (third-year post-graduate prosthodontic residents) with superior color-matching competency participated in the study. Each clinician was screened for color deficiencies using the Ishihara plates. The raters were instructed on the proper use of the vita Tooth guide 3D-master with 29 tabs as per the shade guide's instruction manual. Each clinician carried out visual shade matching separately at the same time of the day and in the same dental office with walls of neutral colors and standardized lighting of 6000 Kalvin using a mobile dental photography device to ensure standardized lighting. Participants were seated on the same dental chair and each examiner performed the shade-matching procedure. Each examiner was blinded to the shade color selected by the other examiner. During the two days, the observations were performed under the same clinical conditions. A new examiner participated in the IOS method to prevent any bias.

Table 1: Shade selection process for every subject on each day

		Visual								
		Observer 1			Observer 2			IOS		
N = x	Day 1	Central (middle third)	Canine (middle third)	Molar (middle third)	Central (middle third)	Canine (middle third)	Molar (middle third)	Central (middle third)	Canine (middle third)	Molar (middle third)
	Day 2	Central (middle third)	Canine (middle third)	Molar (middle third)	Central (middle third)	Canine (middle third)	Molar (middle third	Central (middle third)	Canine (middle third)	Molar (middle third)

For the IOS method, an examiner with 4 years of experience with intraoral scanning participated. The intraoral scanner (trios 3 cartes, 3 shapes) was used and before any measurement, 3D and color calibration using the provided trios color calibration kit was performed. The scanning was done using the same light setting (ambient lighting).

Before scanning, the whole upper arch was slightly dried with an air jet and the scialytic light was turned off. The scanning pattern proposed by the manufacturer was followed. The practitioner began scanning the occlusal surface starting from the second right molar to the second left molars followed by the buccal surface of the second right molar to the second left molar then ending by the palatal surface of the second right molar to the second left molar. After obtaining the scan and making sure that no major or minor holes exist, the shade was chosen prior to the post-processing step. In the presence of any hole, only the concerned area was rescanned. The shade guide on the IOS software was chosen to be the vita Tooth guide 3D master color code and the shade was selected on the middle third portion of each tooth. Post-processing of the scans was of no importance since the shade selection is in the first step and therefore no scans were exported. Shade measurements were exported into excel sheets for statistical analysis. Between each measurement group, 5 min breaks were taken to allow the patient to rest and therefore prevent the mouth and teeth enamel from drying out. The observation days for each patient were separated by one week.

A conversion Table 1 was used to transform the 3D master values obtained in the visual and IOS methods into L, a, and b values in order to calculate delta E.

To assess the repeatability of the IOS compared to the visual method the values obtained on day 1 and day 2 for the IOS and for each observer were compared in the anterior region and posterior region.

As for the agreement rate, the values obtained in the visual and IOS on the same day in the anterior and posterior regions for each color dimension were compared and ΔE was calculated to see if this difference will be clinically acceptable or not.

As for the effect of the tooth position on repeatability, the values obtained in the anterior region and in the posterior region were compared.

Statistical Analysis

Data were collected in excel and transferred for analysis into IBM SPSS Statistics for Windows (version 26) (IBM corp., Armonk, NY, USA). The level of significance was set at 5%. Quantitative and qualitative variables were summarized and presented using means ± standard deviations and frequencies (percentages), respectively. The quantitative variable ΔE was tested for normality using Shapiro wilk test; and Friedman tests were then carried out to compare three dependent means, followed by Bonferroni tests for post hoc comparisons. In order to compare three independent means, Kruskal Wallis tests were used. One-sample tests were carried out in order to assess the significance of the difference between ΔE and the following values: 3.7 which indicates the threshold of perceptibility and 6.8 the threshold of clinical acceptability. To evaluate the association between the qualitative variables, Pearson's chi-square and fisher's exact tests were used.

Results

Results of repeatability assessment between day 1 and 2 for the visual method and the IOS intraoral scanner for all three teeth locations are shown in Table 2. For the central tooth, the visual method (first and second raters) had higher ΔE means compared to the IOS scanner, but this difference was not statistically significant ($p>0.05$).

Contrarily, for the canine and molar teeth, ΔE means were higher for the intraoral scanner compared to the visual method, however, the differences were not statistically significant as well ($p>0.05$). In addition, within the visual method, the differences of ΔE means between both raters were not significantly different for the central, canine, and molar teeth ($p>0.05$).

To evaluate the perceptibility of the difference in color between the first day and the second, ΔE means were compared to the 3.7 thresholds, and the results are displayed in Table 3. For the visual method (presented by two raters) and the intraoral scanner for the three tooth regions, all ΔE values were statistically significantly lower than the threshold of perceptibility ($p<0.05$). Consequently significantly lower than the threshold of clinical acceptability (= 6.8); which makes the differences in color between day 1 and day 2 for the visual method and IOS scanner both imperceptible and clinically acceptable.

Results of the comparisons of ΔE means with the thresholds of perceptibility and clinical acceptability are shown in Table 4; color differences on day 1 and day 2

between the two raters for the central, canine, and molar and between each rater and the scanner for the central at day 2, were significantly lower than the two thresholds. However, on day 1 for the central and canine and on day 2 for the canine and molar (second rater only), color differences between the visual method and the intraoral scanner were greater than the perceptibility threshold but not significantly different from it. Color differences were significantly greater than the perceptibility threshold between the visual method and the scanner on day 1 for the molar (between both raters and IOS) and on day 2 for the molar (between the second rater and the IOS only). All color differences were significantly lower than the clinical acceptability threshold, except between the second rater and intraoral scanner on day 2 for the molar region: The difference was lower than the threshold but not significantly.

Figure 1 displays the frequencies and percentages of matching shades between day 1 and 2 for every rater regarding the visual method and the intraoral scanner for every tooth type. The highest repeatability agreement rate was observed for the IOS for the central tooth (76.3%), followed by the visual method for the canine region (68.4 and 63.2%). Within the intraoral scanner, the repeatability agreement rate was significantly greater for the central, compared to the canine and molar.

Table 2: Comparison of ΔE means between the visual method and IOS between the first day and the second according to three different teeth and within each method between teeth

	Central (N = 38) ΔE (mean ± SD)	Canine (N = 38) ΔE (mean ± SD)	Molar (N = 38) ΔE (mean ± SD)	p-value
First rater (visual)	2.12±2.67	1.34±2.25	1.72±2.09	0.354
Second rater (visual)	1.73±2.41	1.54±2.10	1.93±2.34	0.838
IOS	1.28±2.36	2.37±2.77	2.45±2.67	0.064
p-value	0.475	0.104	0.145	

SD = Standard Deviation IOS = Intraoral Scan

Table 3: Comparison of the difference between ΔE means (between the 2 days) and ΔE threshold = 3.7 for each rater and the intraoral scanner, according to three different teeth

		ΔE (mean ± SD)	p-value
Central (n = 38)	First rater (visual)	2.12±2.67	0.001*
	Second rater (visual)	1.73±2.41	<0.001*
	IOS	1.28±2.36	<0.001*
Canine (n = 38)	First rater (visual)	1.34±2.25	<0.001*
	Second rater (visual)	1.54±2.10	<0.001*
	IOS	2.37±2.77	0.005*
Molar (n = 38)	First rater (visual)	1.72±2.09	<0.001*
	Second rater (visual)	1.93±2.34	<0.001*
	IOS	2.45±2.67	0.007*

SD = Standard Deviation; p*<0.05

Table 4: Comparison between ΔE means and ΔE thresholds (3.7 and 6.8) according to time and the three different teeth

			ΔE (mean ± SD)	Comparison with ΔE = 3.7 p-value	Comparison with ΔE = 6.8 p-value
Day 1	Central (N = 38)	First rater second rater	2.47±2.65	0.007*	<0.001*
		First rater IOS	3.88±2.81	0.700	<0.001*
		Second rater IOS	3.81±2.12	0.757	<0.001*
	Canine (N = 38)	First rater second rater	1.03±1.85	<0.001*	<0.001*
		First rater IOS	4.23±3.56	0.362	<0.001*
		Second rater IOS	4.00±3.00	0.542	<0.001*
	Molar (N = 38)	First rater second rater	1.17±2.06	<0.001*	<0.001*
		First rater IOS	4.91±3.21	0.026*	0.001*
		Second rater IOS	5.13±3.45	0.015*	0.005*
		First rater second rater	1.75±2.29	0.001*	<0.001*
Day 2	Central (N = 38)	First rater IOS	2.56±2.48	0.007*	<0.001*
		Second rater IOS	2.75±2.36	0.018*	<0.001*
	Canine (N = 38)	First rater second rater	1.83±2.16	<0.001*	<0.001*
		First rater IOS	3.48±2.90	0.646	<0.001*
		Second rater IOS	4.19±2.54	0.246	<0.001*
	Molar (N = 38)	First rater second rater	2.25±2.35	0.001*	<0.001*
		First rater IOS	4.82±3.87	0.081	0.003*
		Second rater IOS	6.25±3.87	<0.001*	0.388

SD = Standard Deviation; IOS = Intraoral Scanner p*<0.05

Table 5: Comparison of matching rates between day 1 and day 2 of value, hue and chroma for the visual method and intraoral scanner

		Central (n = 38) n (%)	Canine (n = 38) n (%)	Molar (n = 38) n (%)	p-value
Value	First rater (visual)	29 (76.3)	31 (81.6)	34 (89.5)	0.316
	Second rater (visual)	32 (84.2)	33 (86.8)	32 (84.2)	0.933
	IOS	31 (81.6)^{A}	21 (55.3)^{B}	25 (65.8)^{AB}	0.048*
Hue	First rater (visual)	36 (94.7)	32 (84.2)	33 (86.8)	0.323
	Second rater (visual)	37 (97.4)	36 (94.7)	37 (97.4)	0.772
	IOS	38 (100.0)	33 (86.8)	33 (86.8)	0.065
Chroma	First rater (visual)	26 (68.4)	28 (73.7)	22 (57.9)	0.331
	Second rater (visual)	28 (73.7)	27 (71.1)	24 (63.2)	0.585
	IOS	30 (78.9)	30 (78.9)	30 (78.9)	1.000

p*<0.05; different uppercase superscript letters indicate statistically significant differences between matching rates of teeth within the intraoral scanner (value)

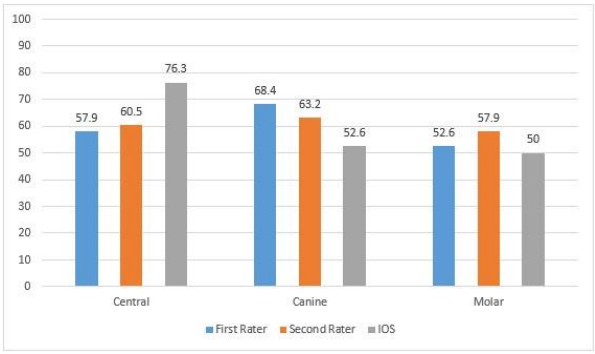

Fig. 1: Comparison of shade matching rates between day 1 and day 2 for the visual method and intraoral scanner

Table 5 displays the frequencies and percentages of matching shades between day 1 and day 2 for every rater regarding the visual method and the intraoral scanner for every tooth type, for the value, Hue, and chroma values. The highest matching rates were observed for the hue value, with the IOS displaying a 100% agreement rate for the central; whereas the lowest matching rates were observed for the chroma values, with the IOS showing again higher agreement rates for all teeth, compared to the visual method. The intraoral scanner showed a significantly greater agreement rate for the value in the central region compared to the canine ($p<0.05$).

Discussion

This study aimed to evaluate the application of the intraoral scanner in dental shade matching while comparing it to the most commonly used technique, the visual one. Essentially, it compared the repeatability of these two methods and the differences in the shades obtained on 38 subjects to assess if the differences were clinically relevant. The results found, when comparing the ΔE values of the two methods, indicated that there was no difference in the repeatability of the IOS compared to the visual method. Furthermore, the difference in the repeatability of each method was significantly lower than the perceptibility threshold. However, the difference between the shades obtained by the intraoral scan and the visual method was imperceptible in the central and canine regions however; in the molar region, the difference was bigger than the threshold of perceptibility. Furthermore, higher repeatability at the central region compared to the molar and the canine regions was observed within the intraoral scanning method. In the current study, the IOS showed high repeatability, especially in the anterior region with the highest repeatability being 76.3%. The repeatability of the scanner was superior to that of the visual method in the anterior region and the scanner was the only method that showed a good agreement between the two days in this specific region. However, when comparing the ΔE of the two methods between day 1 and day 2, there was no significant difference between the IOS and the visual method in terms of repeatability. This finding differs from the results found by Reyes *et al*. (2019). where they reported a superior repeatability of 86.66% between the 3 shape trios IOS and the visual matching technique. This disagreement could be explained by the difference in the scanning protocol and by the variable used to compare the repeatability the investigators compared the percentage of matching between the two methods while our study ΔE was calculated to assess if the difference in the repeatability of the techniques is clinically perceptible. Furthermore, Reyes *et al*. (2019) only scanned the anterior region, whereas, in the present study, a complete scan of the upper arch was performed to simulate the clinical situation. In daily dental practice, the primary use of the IOS is to replace the conventional impression technique; as such, a complete scan was performed in our study so that the impression and shade measurement would be taken simultaneously without any additional tools or steps. Based on the literature search, no standardized method for the use of IOS for shade selection was found, since the scanner's primary use is not intended for color determination. Additionally, unlike all other instrumental techniques designed for shade determination, the IOS does not have a probe that ensures the same positioning of the instrument during the shade-matching procedure (Reyes *et al*., 2019). Hence, this may be a limitation towards the repeatability of the IOS. In fact, multiple

factors may influence the repeatability and, ultimately, the accuracy between the IOS and other types of instruments including colorimeters and spectrophotometers. One of these factors is related to the size of the area under analysis, where the IOS examines the whole crown as one entity using different angles, whereas the latter two instruments determine the shade of only the small area that comes in contact with the probe (Akl *et al*., 2022). Another factor that should be considered when evaluating the repeatability of the IOS is the type of IOS used. Due to the design of the IOS, variations may be observed, between different IOS types with regard to the light source, size of the camera, and the mechanism used to make a digital impression. Since these variations are expected to affect the repeatability and accuracy of the digital impression feature, then the same is anticipated for the shade-matching selection feature (Akl *et al*., 2022). According to the literature, the trio's system is considered one of the IOS devices with the highest repeatability and accuracy due to its HD camera, light source, and the employment of the vita shade guide tabs as reference (Tabatabaian *et al*., 2021). Moreover, the shade guide option used, within the IOS, may affect its repeatability and accuracy (Akl *et al*., 2022). Liberato *et al.* (2019) observed a higher accuracy and repeatability of the trio's IOS when using the embedded vita 3D-master shade mode rather than the vita classical shade one (accuracy, 53.3% versus 27.5%, respectively; precision, 90.3% versus 87.2%, respectively) (Akl *et al*., 2022). This could be explained by the lower coverage error of the vita master shade guide compared to the vita classical (Rutkūnas *et al*., 2020). Due to this difference, only the vita 3D-master shade mode was selected in our study.

Some factors affecting the repeatability of the IOS are related to the features of the tooth rather than the machine itself. The natural tooth is made up of different layers including enamel, dentin, cement, and pulp. Each layer absorbs and reflects the light in a different manner, making it rather difficult to determine the shade of the tooth. As for the non-uniformity in the tooth colors, the incisal, middle, and cervical areas of the tooth may each reflect a slightly different shade. According to a previously conducted study, the most accurate shade is determined by the middle third region of the tooth, since the incisal area may be highly influenced by background color due to its translucency and the cervical area may be highly affected by the light reflected off the surrounding gingiva (Moussaoui *et al*., 2018). As such, in the current study, the shade of the middle labial third area of the tooth was measured to decrease the impact of this variation.

Even though the results provided by the IOS are not highly affected by human factors, such as gender and experience, the IOS is like any other machine which may be affected if the operator does not know how to use it correctly (Akl *et al*., 2022). Unlike the IOS, the visual technique is highly affected by several human and environmental-related factors. To minimize this effect, the lighting condition was standardized in the current study by using a correcting device. This is in line with a previous study done by Gasparik *et al*. (2015) that observed improved shade matching with the use of a light-correcting tool (Gasparik *et al*., 2015). The employment of a light correcting tool, in conjunction with the visual shade guidelines, helped increase the inter-rater agreement, to a certain extent (Liberato *et al*., 2019).

Akl *et al*. (2022), conducted a systematic review of studies assessing the shade selection feature of the different IOS machines versus other shade selection methods, either instrumental or visual. The repeatability observed varied between different studies. While some studies (Sirintawat *et al*., 2021; Reyes *et al*., 2019; Rutkūnas *et al*., 2020; Mehl *et al*., 2017; Yoon *et al*., 2018; Fattouh *et al*., 2021; Brandt *et al*., 2017; Czigola *et al*., 2021), reported a higher repeatability for the trios 3 scanners, using the vita 3D master shade guide, in comparison to both the vita easy shade spectrophotometer and the visual shade selection technique when evaluated in a standardized lighting condition, other studies found similar repeatability between these techniques. Only one study (Ebeid *et al*., 2021) reported unsatisfactory repeatability for the IOS, whereas trios 3, CEREC Omnicam, and CEREC Primescan showed poor repeatability of less than 52%. Of note, the comparator spectrophotometer, the vita easy shade, showed even lower repeatability compared to all three IOS (Akl *et al*., 2022). Another systematic review, conducted by Tabatabaian *et al*. (2021), showed a high repeatability of >85% for the IOS when compared to other shade selection methods.

Regarding the impact of the tooth position on the repeatability of the IOS, when comparing the ΔE values, no significant difference was found ($P = 0.064$). However, when comparing the percentage of matching and mismatching of the IOS, a significant difference was observed between the different regions, with the lowest repeatability measured at the molar region. When looking at these results closely, a calculated p-value of 0.064 for the ΔE difference, is close to the significance and may have reached statistical significance if the sample size was larger. This could be explained by difficulties encountered while scanning this region. Multiple variables, such as scan angles and distance, shadowing of buccal tissues and data overwrite cannot be controlled especially in this area and that could affect the repeatability of the IOS (Moussaoui *et al*., 2018).

In the central region, the IOS reached a repeatability of 100% for the hue dimension, but was less precise for the value and chroma, with a repeatability of 81.6 and 78.8%, respectively. As for the visual method, the lowest repeatability was found to be for the chroma dimension (68.3 first observer and 73.7 second observer). These results matched those observed by Reyes *et al*. (2019), where the

IOS showed higher repeatability for the hue dimension 90%) than the value and the chroma (86.67 and 81.11%, respectively). Both studies have shown a different order compared to the clinical practice, where value is usually the most important of all dimensions in dental shade selection. However, this difference in order is overridden by the higher repeatability of the three dimensions in comparison to the visual shade selection technique, especially in the central region. As for the chroma, this dimension showed the lowest repeatability in both methods (IOS and visual), as observed in both studies. This might be explained, by the visual selection technique, where the human eye has the lowest potential in differentiating between the level of chroma. In addition, when comparing the effect of tooth position on each color dimension, separately, no difference was observed between the different regions for the hue and the chroma; however, a difference was detected for the value dimension with the lowest repeatability being in the canine region. Furthermore, contrary to the central region, the lowest repeatability was observed for the value parameter for both the canine and molar regions (55.3 and 65.8%, respectively). Overall, a difference was found between the values obtained by the IOS on days 1 and 2, and a difference was also noticed between the visual technique on days 1 and 2. Yet, this difference in the repeatability of both methods was significantly below the visual perceptible threshold and hence not perceived by the human eye.

In our study, the accuracy of the IOS was not evaluated. In fact, two main limitations are seen when comparing the accuracy of the IOS. The first limitation is the non-universal approval of the use of the vita easy shade as a gold standard reference instrument for tooth shade selection. The second is that there is not any IOS machine available in the market that gives the shade of the tooth by the CIELAB values. As such, most studies that evaluated the IOS accuracy had to use a conversion table or software to convert the results obtained. In addition, there is no consensus on one conversion chart, where different studies used different charts. The fact that there is no objective method in which the IOS determines a tooth shade and the necessity to use a conversion table, raises a concern about the accuracy of the IOS in comparison with the reference device and, hence, the validity of the obtained results (Akl *et al*., 2022).

In this study, the differences between the shades obtained by the IOS and the visual method, in each of the central and canine region, was found to be below the threshold of perceptibility; these results are in accordance with the study conducted by Mehl *et al.* (2017). However, in the posterior region, the ΔE value between the two methods was superior to the threshold of perceptibility, with a tendency of the IOS to give a lower value. This finding could be explained by the effect of surrounding tissue in the posterior region.

The advantage of this *in vivo* study is that it was done in a controlled environment to minimize the effect of the external factor and to simulate the clinical situation. In addition, the repeatability of the two methods was compared by calculating the delta E and not by assessing the matching agreement rate only. The ΔE was used to be able to evaluate if the difference in the repeatability is clinically acceptable. Furthermore, it evaluated every color dimension separately to determine which of these variables has the least repeatability. Finally, a novel aspect of this study is that it assessed the impact of tooth position on the repeatability of the IOS. Even though the molar tooth is not considered in the esthetic region, the higher demand from the patient and cases where patients have a wide smile makes the restoration color in this region an important factor in its success.

The current study also faced some limitations. The results of the visual shade selection method may have been affected by eye fatigue since no time limits for each shade determination were set; and there were only two observers which could have impacted the results, given the high subjectivity of the visual evaluation and perception of color differences. In addition, although the scanning was done in the same conditions, the lack of light measuring devices to assess the ambient light and temperature may be considered a limitation of the IOS method. Moreover, the scan angle, time, a distance of the scan, and rescanning times in case of holes were not taken into consideration during the scanning process and a full arch scan was done to simulate the clinical reality. Another limitation is that dehydration of the tooth may have occurred while taking the impression. This is of value since tooth moisture is an essential factor when performing shade selection.

To overcome these limitations, future large-scale *in vivo* studies, using a standardized method for color determination using the IOS, are warranted. These further studies may include an additional step for color selection to minimize the influencing factors related to the scanning and may include a reference instrument to determine the accuracy of the measurements in order to expand the knowledge concerning the use of IOS in dental shade selection, a feature for which the IOS was not invented for. Nonetheless, determining the accuracy of the IOS is considered problematic since the scanner does not give the L, a, and b values, and a conversion table is needed.

Conclusion

Based on the findings of this *in vivo* study, the following conclusions were drawn:

1. In the anterior region the IOS showed good repeatability compared to the visual method and the difference between these two methods is clinically acceptable. Therefore, the IOS can serve as a reference for tooth color determination for the dentist and dental technician
2. In the posterior region, the repeatability of the IOS is lower, especially for the value dimension and the human eye could perceive the difference in the shades

obtained by the IOS and visual method. Thus, better to combine it with another shade-matching technique
3. Future studies are warranted to evaluate the intraoral scanner's accuracy

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Author's Contributions

Carine Mounir Ziadeh: Study conception and designed, data collection, interpretation of results; written original drafted preparation.

Pascale Habre: Reviewed and edited.

Lara Nasr: Statistical analysis and result.

Helene Haddad: Study conception and designed, reviewed and edited, director.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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